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STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE
STATE GEOLOGICAL SURVEY

M. M. LEIGHTON, *Chief*

Cooperative Mining Series

BULLETIN 33

RESEARCH NEEDS OF ILLINOIS' COAL INDUSTRY

A symposium relating to recovery, preparation, marketing practice, utilization, and basic research presented at Quarter Centennial Celebration of Illinois State Geological Survey, April 30, 1930

ILLINOIS MINING INVESTIGATIONS

Prepared under a cooperative agreement between the Illinois State Geological Survey Division, and the Engineering Experiment Station of the University of Illinois

Published in cooperation with the Illinois Coal Bureau



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

1930

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M. F. WALSH, *Director*

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PREFACE


The papers printed herewith were presented at the Symposium on "*Research Needs of Illinois' Coal Industry*" at the Quarter Centennial Celebration of the Illinois State Geological Survey, April 30, 1930, the Engineering Experiment Station of the University of Illinois cooperating. As will be seen, they were prepared by specialists in their different fields and are futuristic in their general trend; therefore they are being issued for the consideration of all who are vitally interested in the coal industry of Illinois.

We gratefully acknowledge the kindly interest and offer of the Illinois Coal Bureau to share the expense of publication.

It is, of course, understood that the authors alone are responsible for the facts and opinions expressed in their respective papers.

M. M. LEIGHTON, *Chief*
Illinois State Geological Survey

Urbana, Illinois
May 6, 1930



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THE FUNCTION OF RESEARCH IN INDUSTRY

By Milo S. Ketchum ¹

INTRODUCTION

In the summer of 1928 when in London, I visited, among many other interesting places, the British Museum. The industrial exhibits in this museum indicate that the ancients were well versed in many of the industrial arts and that many of the ancient artisans were especially skillful. The ceramic industries were especially well represented. Due perhaps to the fact that the knowledge of these arts was in a few hands, the knowledge was lost with the passing of the individuals possessing the information.

The development of industrial nations has been largely due to a revival of the arts and crafts and the application of science and invention. In a great measure, the industrial activity in Great Britain was due to a knowledge of the methods of manufacturing steel and iron, Portland cement, and the other materials used in machines and structures.

In the beginning, most of the research was carried on by the individual industries, and the results of course were used by the industries for private gain. As the industries developed, however, it was found profitable to carry on the investigations through the cooperation of the members of a group of industries, either in public or private laboratories.

Research investigations may be of several kinds. Each manufacturer has production problems which are of special interest to him alone. These he can best solve in his own plant. There are other problems that are of peculiar importance to the entire industry. These include the development of equipment, standards of quality and workmanship, and they can best be conducted on a cooperative basis.

DEVELOPMENT OF ENGINEERING RESEARCH

In the United States, engineering research investigations are now being carried on in the laboratories of many of the industries, in private commercial laboratories, by the federal government in such laboratories as the Bureau of Standards, in state laboratories, in the laboratories of state universities, and in privately endowed colleges and universities.

¹ Dean of the College of Engineering and Director of the Engineering Experiment Station, University of Illinois.

The first engineering colleges in the United States were virtually liberal arts colleges with a few subjects covering the art and science of engineering. As a result of the Morrill Act, Land Grant colleges and universities were established in practically every state in the Union, and in these institutions the engineering curriculum was given a place comparable with that of liberal arts and agriculture. With the engineering college as a separate entity, engineering research has developed in a wonderful way in Land Grant and state institutions.

The first regularly organized engineering experiment station was established at the University of Illinois on December 8, 1903. In 1904 an engineering experiment station was established at Iowa State College. The number of engineering experiment stations has increased very rapidly since that time and there are at present thirty-six engineering experiment stations in land grant institutions. In addition, there are a number of engineering experiment stations in state universities which are not land grant institutions, and a considerable number of engineering experiment stations are in endowed colleges and universities.

WORK OF AN ENGINEERING EXPERIMENT STATION

SCOPE OF WORK

An engineering experiment station in a state university must carry on its investigations for the benefit of industry and ultimately for the benefit of the public. This limitation naturally restricts many of the investigations that can be undertaken by these experiment stations. At the University of Illinois in all cooperative investigations, the University reserves the right to carry on the investigations, in its own way with assistants employed by the University. It also reserves the right of publication, and all inventions and discoveries belong to the University.

In carrying on engineering research, it is oftentimes necessary to develop new processes and new methods. If the scientific knowledge at hand is inadequate, it may be necessary to undertake investigations in pure science in order that the problem can be solved.

Engineering research differs from so-called "pure" research in that the principal aim of the former is to solve some definite problem. Ordinarily, engineering research is conducted on a somewhat larger scale than research in pure science. If the methods or knowledge available in pure science is not sufficient for our purpose in engineering research, new methods and new data must be obtained. In many cases, this makes it necessary to carry on very extensive investigations in the

field of pure science. For example, in the investigation of fissures in steel rails now in progress at the University of Illinois, it has been necessary to develop a new method for the mathematical analysis of the stresses in the head of the rail.

When structures and machines were of simple character, a knowledge of the common physical properties of steel was adequate for design and construction, but with the tremendous increases in requirements in modern industry, in pressures, speeds, temperatures, and similar essentials, this elementary knowledge of properties of materials became quite inadequate.

For several years Professor H. F. Moore at the University of Illinois has carried on investigations in the fatigue phenomena of metals, which has been financed by the Engineering Foundation, the General Electric Company, and several other companies. The results of Professor Moore's investigation have given the Engineering Experiment Station and Professor Moore world-wide recognition. One of the faculty of the University of Liverpool spent more than a year in Professor Moore's laboratory, and last year a professor from the University of Budapest spent several months working under the direction of Professor Moore.

COOPERATION WITH INDUSTRIES

Although it is necessary that the permanent staff of an engineering experiment station be supported by the state or by the institution, it is not possible to carry on all the needed lines of investigation in the Engineering Experiment Station without the cooperation of the industries. At the present time, the State of Illinois is furnishing nearly \$100,000 for the support of the Engineering Experiment Station, but in addition to this, more than \$150,000 a year is being furnished by various industries to carry on 36 special cooperative investigations which are of especial value to them. These investigations are carried on with a staff of men working on full time, with many others working on part time.

TRAINING OF RESEARCH WORKERS

The research graduate assistants at the University of Illinois are part-time workers, whose services are invaluable in the work of the Station and whose training on these investigations under famed investigators is invaluable to themselves. They are appointed for two years and give one-half their time to research and one-half their time to grad-

uate study. More than one hundred of these research graduate assistants have completed their work and have received either the degree of Master of Science or of Doctor of Philosophy. These men have been uniformly successful and are now occupying positions of responsibility with the industries, in research, and with educational institutions. Although the results of the various researches carried on in the Engineering Experiment Station of the University of Illinois have been of great value to the industries, there is little question but that the men trained in the Station have been worth a great deal more than the data obtained in the investigations.

PUBLICATION OF RESULTS OF RESEARCH

The results of the research investigations in the Engineering Experiment Station of the University of Illinois are given in more than two hundred bulletins and circulars published by the University. These bulletins cover investigations of materials, including cement, steel, and ceramic materials, and many others on problems pertaining to the mining industry.

Two of the early bulletins published in cooperation with the State Geological Survey appeared in the very early days of the Engineering Experiment Station, one "Investigation of the Fire Clay of the State," by R. C. Purdy and F. W. DeWolf, was published in 1906, and the second, "Paving Brick and Paving Brick Clays of Illinois," by A. N. Talbot, I. O. Baker, C. W. Rolfe, and R. C. Purdy, was published in 1908.

As early as 1911, the Engineering Experiment Station cooperated with the federal Bureau of Mines and the Illinois State Geological Survey Division in carrying on research in the coal resources of the State. In 1926 the Bureau of Mines withdrew from this cooperative arrangement, but the Geological Survey and the Engineering Experiment Station are still cooperating on these very important problems.

As a result of this cooperation, a great many valuable bulletins have been published on the coal resources of Illinois. Nine bulletins and nine technical papers have been issued by the U. S. Bureau of Mines. Twenty-three bulletins have been published by the Geological Survey Division, and twenty-one by the Engineering Experiment Station. Several of the more recent bulletins published by the Engineering Experiment Station on the cooperative mines work are: No. 158 "The Measurement of Air Quantities and Energy Losses in Mine Entries," by A. C. Callen and C. M. Smith, No. 170 "The Measurement of Air Quantities and Energy Losses in Mine Entries," Part II, by A. C. Callen and C. M. Smith, No. 184 "The Measurement of Air Quantities and Energy Losses in Mine Entries," Part III, by A. C. Callen and C.

M. Smith, No. 196 "An Investigation of the Friability of Different Coals," by C. M. Smith, No. 199 "The Measurement of Air Quantities and Energy Losses in Mine Entries," Part IV, by C. M. Smith.

The publications of the Engineering Experiment Station include many other bulletins besides the coal mining bulletins, which are doubtless of interest to the mineral industries. For instance: "The Thermal Conductivity of Fire Clay at High Temperatures," "Dissolved Gases in Glass," "The Viscosities and Surface Tensions of the Soda-Lime-Silica Glasses at High Temperatures," "An Investigation of the Translucency of Porcelains," "The Measurement of the Permeability of Ceramic Bodies," "A Study of Hard Finish Gypsum Plasters," "The Thermal Expansion of Fireclay Bricks," "A Laboratory Furnace for Testing Resistance of Firebrick to Slag Erosion."

In conclusion, may I express our very great appreciation of the sympathetic support and able cooperation of the State Geological Survey Division which we have always enjoyed in our joint investigations of the coal mining problems in Illinois. We trust that the work has been mutually profitable and that it will continue indefinitely under the same pleasant arrangement, to the great benefit of both geology and engineering.

A MINING ENGINEER'S VIEW OF THE FUTURE OF ILLINOIS' COAL INDUSTRY FROM THE STANDPOINT OF RECOVERY

By John A. Garcia ¹

PURPOSE AND SCOPE OF THIS ARTICLE

It is the purpose of this discussion to submit the opinion of a Mining Engineer as to how the Geologist may best serve the coal mining industry in planning his schedule of research or investigation for the next several decades. The idea was prompted by the realization that the rapid depletion of those seams of coal in Illinois whose characteristics, from the standpoint of both combustion and mining, lead to immediate exploitation, will soon bring up the problem of substitution when these better coals are exhausted.

COAL RESOURCES

Because of our wasteful mining system it is estimated that the 120 billion tons, more or less, of coal under the prairies of Illinois will last only about 375 years, but our best seams have a much shorter life if present mining and combustion methods are continued.

From Bulletin 15 of the Cooperative Agreement ² we find the available coal from the No. 6 seam in District No. VI to be about five billion tons at a 56 per cent extraction, and Bulletin No. 19 ³ cites in District No. V a total of about three billion tons at 60 per cent extraction for both No. 5 and No. 6 coals. Those two districts embrace Franklin, Williamson, Jefferson, Saline and Gallatin Counties, an area from which comes the coal generally considered to be of the highest quality in the State. The combined available coal resources of the two districts is approximately eight billion tons.

¹ Allen and Garcia Company, Chicago.

² Cady, G. H., Coal Resources of District VI: Illinois State Geol. Survey, Coop. Mining Series Bull. 15, 1916.

³ Cady, G. H., Coal Resources of District V: Illinois State Geol. Survey, Coop. Mining Series Bull. 19, 1919.

The low sulphur area in Franklin County was opened up in 1904 and the production mounted rapidly through the years until today it is one of the leading, if not the leading county in the output of Illinois coal. The decline in production from longwall mines coincided with the increase from the thick seam district, as might be expected when the difference in mining cost, as well as quality, is considered, but the shift in production was so rapid and radical that the whole economic structure of the industry was changed.

The following table illustrates this history-making epoch in Illinois mining and indicates clearly the intensive exploitation of our best coals:

TABLE 1.—*Coal production in La Salle and Franklin counties, showing the southward shift in production*

		La Salle County Tons Produced	Franklin County Tons Produced
1904		1,773,000	None
1910		1,302,000	2,071,000
1915		1,274,000	7,324,000
1920		865,000	11,300,000
1925		641,000	13,082,000
1929	(approximately)	334,000	14,720,000

EXTRACTION

The mining conditions in La Salle and Franklin Counties are, of course, totally different. In La Salle County coal No. 2 is about $3\frac{1}{2}$ feet thick and is worked by the longwall method of mining, whereas in Franklin County the No. 6 seam averages 9 feet in thickness and is worked by the room-and-pillar or panel system. The percentage of extraction for La Salle may be taken at 95, but for Franklin County No. 6 seam it varies from 40 to 50.

The following figures on coal losses and extraction are summarized from the tables presented by C. A. Allen⁴ and were compiled after a comprehensive and systematic survey by the Commission:

⁴ Allen, A. C., Coal losses in Illinois; Illinois State Geol. Survey, Coop. Mining Series Bull. 30, 1925.

TABLE 2.—*Summary of coal losses in Illinois*

Reason for Loss	Peoria and Fulton Coal No. 5	Central & Belleville No. 6	Spring field Nos. 5 and 6	South-ern Ill. No. 6	Saline County No. 5	Dan-ville Nos. 6 and 7	Long-wall No. 2
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Left as roof and bottom coal.....	None	0.7	Fraction of 1	7	None	None	Fraction of 1
Room, entry and panel pillars.....	35	43.0	44	41	38	32	None
Oil and Gas-well pillars	None	None	None	None	None	.....	None
Bldg. R.R. and boundary pillars.....	.....	0.8	.....	1	.....	.....	Fraction of 1
Mining and preparation loss.....	3	2.7	4	3	3	4	5
Rolls, thin or dirty coal, faults, streams, etc..	15	0.3	3	1	5	7	None
TOTAL LOSS.....	53	47.5	51	53	46	43	5
Avoidable Loss.....	28	26.0	26	36	31	23	0
Possible to extract.....	75	77 to 80	75	83	85	80	.....
Average present extraction.....	47	52.5	49	47	54	57	95

Illinois—Exclusive of Longwall Field

Average Extraction 50.3 per cent
Average Loss 49.7 per cent

100.0 per cent
Avoidable Loss 32 per cent
Possible to Extract..... 82 per cent

If this 32 per cent were saved, the depletion charge on coal acreage would decrease about 25 per cent—enough to pay for surface rights in most sections of Illinois.

Although this table indicates only a small variation of from 47 to 57 per cent extraction in the different districts employing the room-and-pillar method, the fact is that a much wider range exists between individual mines and even districts. The calculations, or estimates, made by the authors of the many publications examined by the writer were probably as accurate as possible considering the many varying factors involved in the problem and the meager data available, but the figures were all compiled from operating or live mines and one very large source of lost coal was not considered; that is, the abandoned acreage in mines that fail, for one reason or another, to reach what might be termed the economic limit of assigned acreage. There are many such

abandoned mines in Illinois and Indiana and most of them leave strips or tracts of coal acreage beyond the faces that cannot be worked from other mines, as shown in Figure 1.



FIG. 1. Showing abandoned mines and lost boundary coal.

Probably the best way to secure reliable data on extraction percentages is to make an accurate survey of a mine when abandoned, planimeter the meandering line of the working face for acreage de-

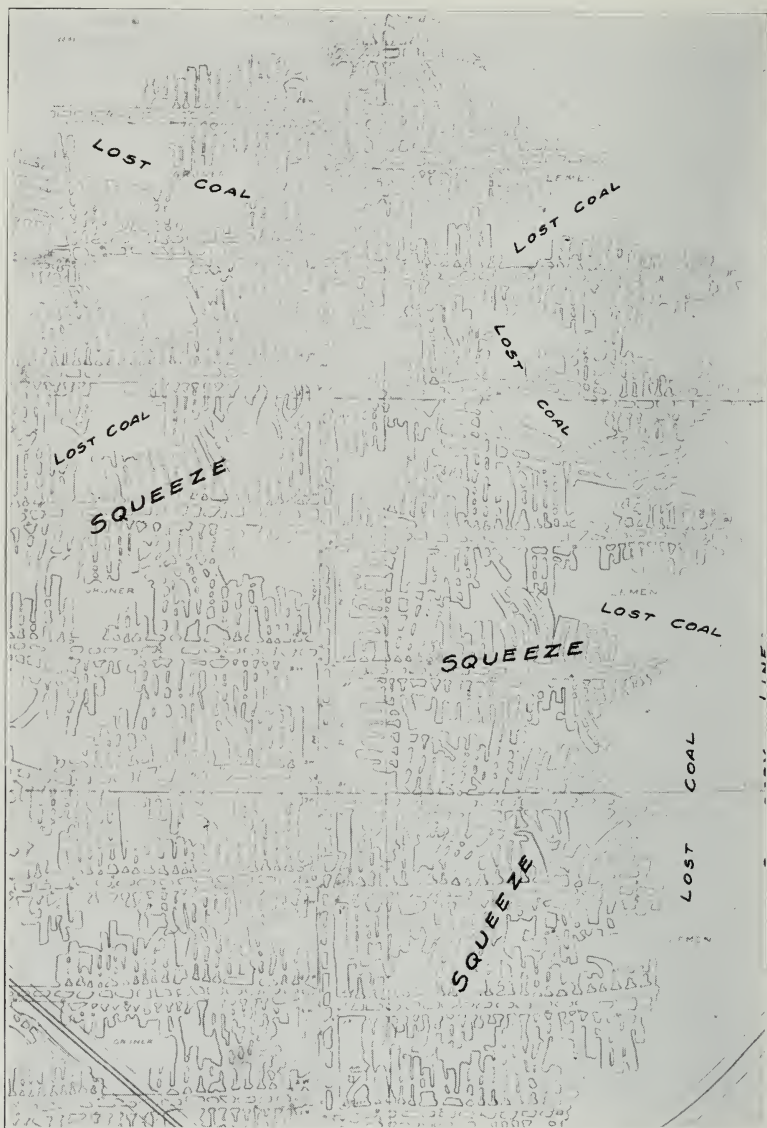


FIG. 2. Workings of an abandoned mine illustrating lost coal areas due to non-systematic layout and squeezes.

pleted and take the hoisting record for tons produced. From these basic data can then be calculated the tons per acre extracted and the loss of boundary coal. By systematic measurements in all parts of the mine a

fair average thickness of the seam may be arrived at which would permit of calculating within reasonable limits the actual percentage of extraction over the whole period of the mine's life, which is the real base to use when figuring extraction. It may be stated here that in the writer's experience very few room-and-pillar mines in Illinois, of any size, have averaged throughout the life (or over a substantial period of years) an extraction of 56 per cent which is the "rule of thumb" figure used in this section of America and reached by the simple rule of 1,000 tons per foot per acre. Close examination and inspection of many properties for the purpose of making engineer's reports for financing, places the percentage at an average of less than 50 and in some of the most ambitious operations in Illinois, near 40. (See Fig. 2.)

REASONS FOR LOW EXTRACTION PERCENTAGES

There are some excuses, but many good reasons why the coal operator of Illinois loses more than half his acreage in winning the coal. Mismanagement, carelessness, and ignorance account for only a small part of the total loss, for the Illinois mining man ranks near, or at the top, of the list as to competency and application. The economic and labor conditions, however, together with the necessity of producing coal at an extremely low cost forces him to forget, or at least defer, the day when he may establish systematic pillar drawing or "robbing."

To keep this paper within reasonable limits of its scope, only a few of the major reasons for the Illinois mining man's alleged "disgraceful" waste of our coal resources are cited.

First, the contract with labor which imposes a premium known as "yardage price" on all narrow or development work. It is quite impossible to design a mining system without liberal use of "narrow" places and the application of yardage costs, together with other contract requirements forces maximum percentage of wide places in a given area if competitive costs are to be obtained. (Fig. 3.)

Second, excessive surface cost per acre allowed by the courts in damage suits for subsidence or the alternate burden of "carrying charges" and taxes on surface land should the operator purchase his acreage in fee. The average cost of Illinois surface land is higher than that of most other coal producing states.

Third, the increased amount of screenings or small size coal made by increasing the percentage of narrow work and by pillar drawing.

Fourth, the intermittent running time at Illinois mines, for an im-



FIG. 3. Typical panel system at a modern Illinois mine illustrating ratio of wide to narrow places also so-called "pillar drawing."

portant element in the plan of systematic pillar-drawing is continuous operation. Any extended period of mine idleness would be nearly fatal to such methods.

WHAT THE FUTURE SHOULD BRING

The geologist can be of assistance to the mining industry, in the solution of these four problems affecting extraction by compiling, in one volume, old and new data bearing on these questions and possibly by using proper influence to correct the evils in court procedure in subsidence cases. The mining engineer's answer to the whole problem is complete mechanization and plants for cleaning the output.



FIG. 4. New mine in Pennsylvania workings designed for 95 per cent recovery and complete mechanization.

The establishment of rib-robbing lines and systematic pillar-pulling is a fairly simple problem for practically all Illinois coal mines and there would be very little experimental methods involved, excepting as to minor details, in adapting one of the many established systems to the special conditions of the individual operation. Complete mechanization for drilling, cutting, loading, hauling, hoisting, and preparation means rapid advancement of development work, with resultant concentrated mining, and though it also means a dirtier primary product, the mechanical cleaner can correct that. (Figs. 4, 5 and 6.)

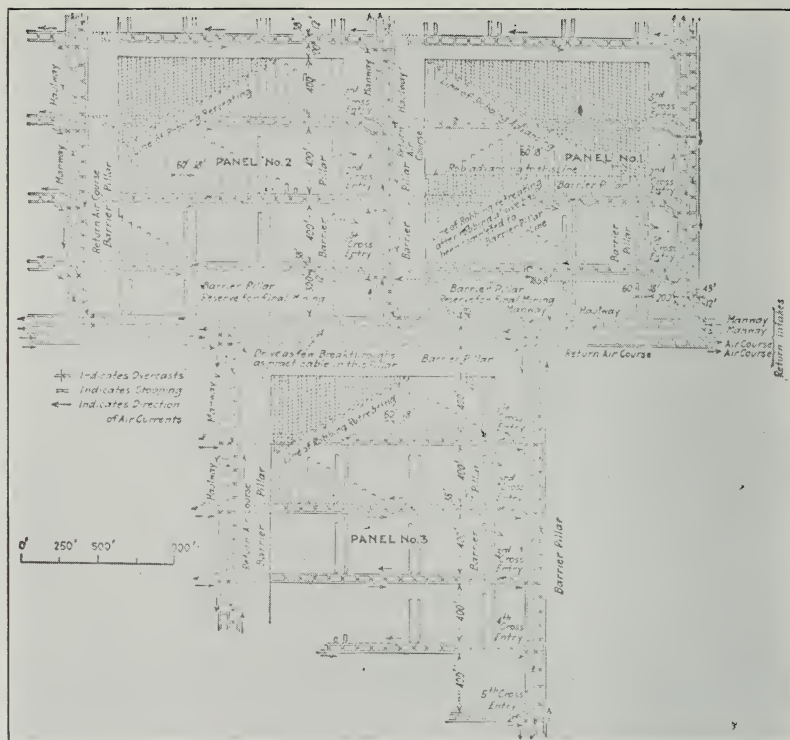


FIG. 5. A West Virginia mining plan showing panel system designed for 95 per cent recovery.

The geologist is directly concerned, for many reasons, in the successful introduction of loading machinery in Illinois mines and in the development of equipment for cleaning coal and particularly because seams not now worked, due to non-competitive conditions with hand-loading, may be very profitably worked with complete mechanization. It is readily conceivable, therefore, that the thinner coal seams of Illinois, especially those with low freight rates to the general markets, may come back into the picture, and it behooves the geologist to "dig and discover" those characteristics of such coal beds as lend themselves to ready application of mechanical operations, characteristics such as levelness, roof, faults, water, surface topography, little affected by subsidence, etc.

The screenings problem must be solved by the chemist and combustion engineer and they have gone a long way in the last ten or fifteen years. Until 1899, the percentage of screenings at Illinois mines averaged 25 per cent of the output, but in that year the mine-run basis of

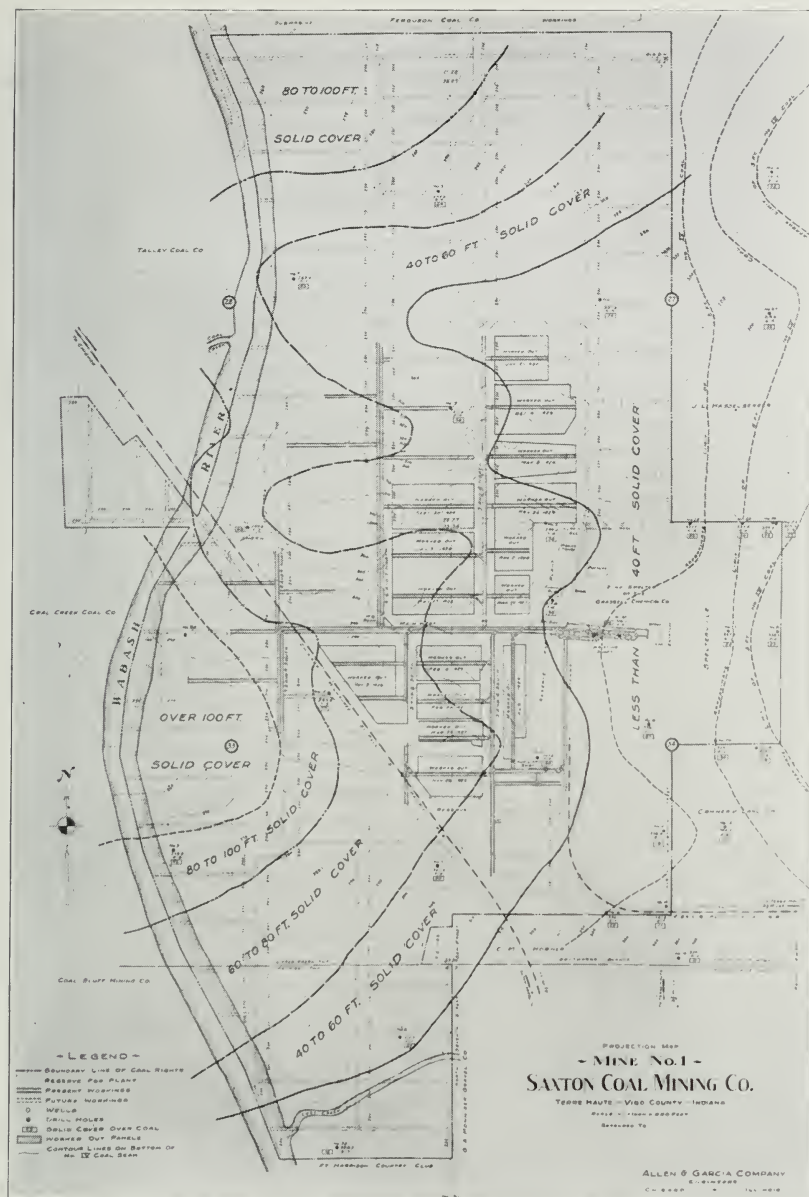


FIG. 6. Panel system of an Indiana mine designed for 50 per cent recovery on account of water bearing overburden.

payment was adopted and the percentage of small coal rose abruptly to 55 per cent. From 50 to 55 per cent of two-inch screenings has been normal at most mines ever since. This situation was met by the mechanical engineer in the design of special equipment for burning screenings, such as stokers, powdered coal apparatus, forced draft, etc., and in the last few years, the stoker for domestic use. It is true that in the last 25 years the amount of coal used to generate a kilowatt-hour has been reduced from five pounds to almost one, thereby further limiting the market for screenings, but this has been offset by the enormous increase in the production of electric energy, whose volume curve goes up sharply each year and will surely continue to rise until the demand for screenings will automatically eliminate the differential in price between lump and small coal.

When the chemist or metallurgist has done his part and low-temperature distillation of Illinois coals has become feasible commercially, the mining engineer and the geologist will have opened to them new fields to conquer, for if we may be permitted to design and build a coal mine to produce screenings only, we will have reached our ideal in operation and the geologist will be confronted with the task of developing new data on old coal fields to be studied in the light of such radical changes in mine requirements.

EXTRACTION AND STRIP-MINING

This very important branch of the industry is now a factor to be reckoned with as may be noted from the following production table for Illinois alone:

TABLE 3.—*Percentage of coal produced by strip-mining*

Year		Output	Percentage of State Total
1914		324,487	Negligible
1917		542,801	.6
1922		720,060	1.2
1924		2,295,860	3.4
1926		3,461,098	5.0
1928		4,345,000	8.0
1929	(Approximately)	5,104,653	9.0

In the United States, approximately 20,000,000 tons of coal is now won in a year by the stripping method—about 4 per cent of the total bituminous output—and undoubtedly this percentage will increase for some years. The extraction in the Illinois pits may be fairly averaged at 85 per cent, although some operators claim 95 or even 100 per cent,

but intimate contact with many pits has convinced the writer that 85 per cent is the more conservative figure, especially for very thin seams where an inch or so of bottom coal may be 5 per cent or more of the whole, thus radically affecting the ratio of extraction. The ribs along the spoil bank, faulty areas, tracts inaccessible on account of shape, severe grades, etc., all combine to make a sizable total and must be considered in calculating extraction. (Fig. 7.)

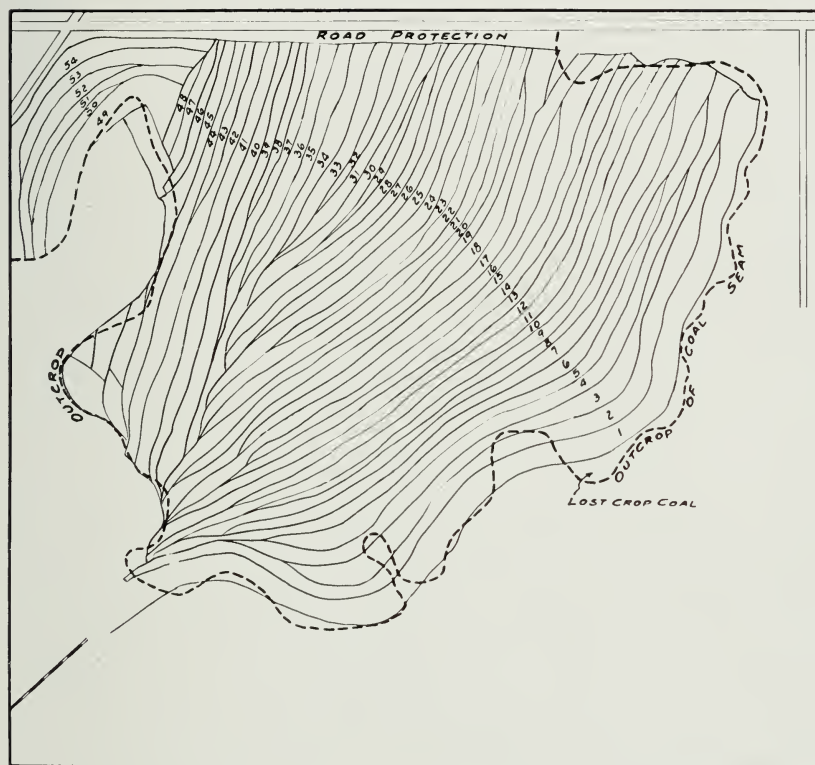


FIG. 7. Map of modern strip pit showing high percentage of recovery. Each cut is indicated as actually made.

Splendid service has been rendered the strip coal operator by the geologist and the industry has profited greatly by the publication of such Bulletins as Nos. 28, 31 and 32, of the Cooperative Mining Series. The recovery of many millions of tons of Illinois coal was hastened as a result of these studies and prospecting costs were much reduced.

Although a bulletin on "Coal Stripping Possibilities in Southern and Southwestern Illinois,"⁵ was issued in 1927, it appears as though a supplementary report will be needed in a few years because of the great strides made each year by the manufacturers of equipment for this class of work, making possible the profitable exploitation of thin seams having a high ratio of overburden but located close to markets. In the northern Illinois field, the thin No. 2 seam is now stripped where ratios of overburden to coal are as high as thirteen to one, and by supplementing the digging shovel with drag lines, several of these pits will soon be operated where the ratio is twenty-to-one, but this is exceptional and possible only because the overburden requires no shooting and the market is practically right at the pit.

Up to sixty feet of cover is removed today, where forty was the limit ten years ago, and large tracts with a stratum of hard rock in the overburden are readily stripped by the present huge shovels and with the generous use of explosives, whereas, in 1920, or even 1925, such areas were not considered desirable. Drainage system, pumping equipment, purchased power, pit car design, liquid oxygen, and numerous other items of improvement have made it necessary for us to revise our preconceived ideas of possible strip areas, and our data as listed in publications available at the present time may be obsolete in a few years, insofar as potential strip acreage is concerned.

STORAGE OF COAL

The State Survey has done some very fine work in connection with coal storage and much valuable data have been published. This question is related to extraction, in that when a mine is mechanized, pillar drawing and rib-robbing lines will be much more practicable and profitable, but this, in turn, demands fairly continuous operation. Now, should the modernization schedule follow its proper sequence and production of lump coal become a minor instead of a controlling factor as at present, the mechanical features in the design and layout for coal storage will be greatly simplified. Add to this the mechanical cleaning of small sized coal and elimination of depreciation in values because of degradation, then storage—both ground and under water—becomes more a question of financing costs than an engineering problem.

In Europe efficient utilization and storage of coal has always been given more consideration than in America, chiefly perhaps because of the comparative investment and production costs and limited natural resources, but we must put an end to our waste of better grade coals or

⁵ Cady, G. H., Coal Stripping Possibilities in Southern and Southwestern Illinois: Illinois State Geol. Survey, Coop. Mining Series Bull. 31, 1927.

we shall face the same situation. The writer's work in Russia has to do with the construction and development of coal mines and in each instance the plans include mechanization, cleaning plants, 75 to 90 per cent extraction of each workable seam, and storage of output at the mine to permit steady hoisting in event of car shortage whether due to slow market for certain sizes or to other causes that interrupt operations. In some instances, backfilling by pneumatic or a water flushing system must be provided to protect against subsidence or to aid in obtaining high extraction percentages.

SUMMARY

In view of the foregoing, it is suggested that the geologist henceforth collect and present his data with special consideration for the effect that mechanization, cleaning plants and new methods of utilization will have on the present mining methods of Illinois. He should continue to furnish information that aids in prospecting and to publish reports, maps, folios, etc., for these are practically indispensable today for the intelligent projection of workings or planning of new operations. Mining systems used in other states showing pillar-drawing methods might well be studied to determine those most suitable to Illinois conditions. He should assume that when this era of factory process shall have arrived, concentrated mining with resultant high percentage of extraction will be part of the program, and from his intimate knowledge of the characteristics of each Illinois coal seam he should be able to build up a table showing the possible available tonnage from Illinois coal measures under the proposed system, and demonstrate by comparison with the figures compiled in conformity with present practice, the great increase in fuel resources and life of existing mines.

It does not mean much to the average layman for the geologist to tell him we have a hundred billion tons or so of available coal in Illinois and that it will last three or four hundred years, but it does mean something when you say that with more modern methods of mining and processing of output, we could increase our fuel resources fifty per cent, decrease the cost to the ultimate consumer, and give him a lower ash coal. Also, it would mean a great deal to the coal operator if the geologist would show on his maps those areas where the seams, because of physical conditions and location relative to market, indicate successful exploitation with complete mechanization and the consequent decrease in amortization charges due to higher extraction and longer life.

CONCLUSION

It appears certain that we of the coal mining industry of Illinois are at the threshold of the door that opens to new and greater opportunities. The passing generation of coal men has had no easy path; there have been cycles through the years when great momentary prosperity brought hysteria and then—long periods of depression and distress. With the geologist to point the way, the engineer to direct the methods of extraction, and with a sound economic structure, it is possible to almost double our precious heritage of coal and in that thought lies the inspiration for further cooperation and renewed effort.

COAL PREPARATION AND RESEARCH FOR FUTURE NEEDS

By E. A. Holbrook ¹

COAL PREPARATION RESEARCH

Eighteen years ago the writer, while engaged in teaching and research work in Nova Scotia, was visited by the late Dr. H. H. Stoek, who stated that research in coal preparation was one of the visions he had for his newly established department of Mining Engineering at the University of Illinois. "Certainly," he said, "since research has so advanced the preparation of ores and other minerals, there must be a field for similar work in coal." The next fall the writer came to the University of Illinois and during the following five years was connected with the University, devoting part time to coal preparation investigations under Dr. Stoek. Later this work was conducted by Professor Ray Arms, and through cooperation with the U. S. Bureau of Mines, by Mr. Thomas Fraser and Dr. H. F. Yancey. Since then the work has been carried on under the direction of Professor A. C. Callen.

Out of the research work in coal preparation at Illinois has come technical knowledge that has made possible new methods and machinery in coal preparation; for example, the application of the so-called Concentrating Table to the cleaning of fine coal, and a knowledge of the relative importance of sizing in coal cleaning operations. Several advances in the art of screening resulted from work in the laboratory. During the war, methods of recovering pyrite from various Illinois coals were developed to a point, where, had the need for sulphur continued, a considerable number of plants would have been in operation. Later a successful coal cleaning table using air as a separating medium was perfected and the principle of the so-called air-sand separation process was worked out. Advances were made in our knowledge of the so-called float-and-sink test in coal preparation, and the now familiar washability curves were perfected from which the probable success or failure of a coal cleaning operation can be forecast. Again, progress in developing the laws of breakage or degradation of coals made in the laboratory here has promising applications.

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The value of the coal preparation laboratory at the University of Illinois has been not alone in its technical productions, but rather, its greatest values have been in the interest its work has aroused elsewhere on the subject, and by the compilation of a series of bulletins and technical articles which have been guideposts for other investigators and for commercial industry. For a number of years the Illinois laboratory was the only non-private laboratory devoting its attention to coal preparation; and its stimulus has been felt in every coal field of this country and abroad.

As an illustration, about fifteen years ago the writer was at a mining convention where the results of certain work of the Illinois laboratory were given. The audience consisted of four men. Two years ago at a mining convention at Cincinnati practically the same ground was covered in a paper, but to an audience of nearly 400 representing every part of the coal mining industry, all eager to hear and to discuss the paper. Professor Stoek's vision of the importance of coal preparation to the industry is being realized today by the commercial industry after the ups and downs of nearly twenty years. Coal preparation plants have been installed in the past year or two, having an individual capacity of more than 8,000 tons daily, and subject to scientific and engineering control on a par with our most advanced industries. Compared with the crude rule-of-thumb coal preparation plants of twenty years ago, they represent a new era in coal preparation. The coal preparation laboratory at the University of Illinois cannot of course, take credit for this advance, it is due to the work of hundreds of men and to many organizations. However, in the compilation and issuing of data and by encouraging research and exact knowledge in the field of coal preparation, the University of Illinois laboratory has many times justified the vision of Dr. Stoek.

The term "coal preparation" generally means either the removal of impurities from the coal or the sizing of coal after mining and before utilization, or some combination of these distinct operations. Twenty years ago Illinois ranked first or second among all the states in the quantity of coal washed or prepared for the market by the removal of impurities. Today a number of districts have outstripped Illinois, not only in amount of coal cleaned, but in the introduction of improved methods. In actual screening and sizing of coal Illinois lead all the bituminous coal producing states and was second only to the Pennsylvania anthracite field. Today these processes have been widely copied and greatly improved. There is scarcely a bituminous coal producing district in the country that does not make a real effort to prepare its coal as to size and purity to meet the competitive market demands. It used

to be considered that many coals were of such a nature that they were not benefited by the washing processes then in existence. Today with the modern coal jigs, with the various air separators, with the Chance sand process, The Rheolaveur process and with the adaption of the flotation and other processes to the coal cleaning problem, there is probably not a single coal containing its impurities in visible size that is not amenable to some one of these processes. In screening and sizing it seems that with the perfection of the modern shaking and vibrating screens the ultimate in this phase of preparation has been reached. In other words the technical progress in coal preparation during the past ten years has been so great that it will take the commercial industry many years to take full advantage of it. Technically many of the urgent problems of coal preparation have been solved; the near future demands more the working out of these processes to individual coals at a low enough cost so that the industry can afford to use them. Perhaps the exception to this rule is pulverized coal. More and more bituminous coal is pulverized to a powder before being burned. Theoretically this finely divided coal is in an ideal state for removal of impurities, inasmuch as the pulverization has freed the coal from the adhering impurities, but practically no process has been perfected which will clean this pulverized coal. Perhaps the solution lies in an air blast of varying velocity. At any rate the practical solution must be simple and cheap. The problem offers a real challenge in coal preparation.

Altogether, the most interesting developments today in coal preparation research are the following:

(1) Development of oil flotation of coal by the use of an alkaline circuit which permits the separation of the finely divided pyrite from the coal.

(2) Success in settling and clarifying the black water discharge from washeries by the use of starch and caustic soda.

(3) Realization that the removal of inerts or impurities in the fine sizes of coal has an important bearing in the physical structure of the resultant coke, especially in reduction in the so-called coke breeze.

RESEARCH FOR FUTURE NEEDS

Coal preparation in its broadest sense, is vastly wider in scope than sizing or even in taking out of the coal, visible impurities. It has been wisely remarked that coal has been discovered three times as follows:

First—as a raw fuel or source of heat.

Second—as a substance to be manufactured into coke and by-products.

Third—as a base for new chemical industries.

All of these certainly deal with coal preparation but in widely different senses. Let us consider them in order.

(1) *Coal as a raw fuel or source of heat.*—When we deal with coal as a raw fuel or source of heat we are concerned with cost, efficiency and general cleanliness. Education of the user as to relative cost and efficiency of prepared vs. unprepared coal is the most important step to promote the more general use of coal preparation plants. The worst feature of raw coal today, aside from smoke, is its general dirtiness. It is interesting to note that during the past year or two a number of coal companies and large numbers of retail dealers have adopted the plan of wetting down their coal with a solution of calcium chloride before shipping to the consumer. The plan actually seems to keep down dust and dirt, presumably by taking advantage of the delequescient property of calcium chloride. Perhaps further investigations might discover a more advantageous method of preventing dust, with a consequent increase in popularity of soft coal. It seems only a step further to add some substance to the raw coal which might prevent the formation of soot in chimneys. Apparently these are simple troubles and yet their solution would go far towards eliminating prejudice against soft coal.

(2) *Coal as a substance to be manufactured into coke and by-products.*—Some sixteen years ago I sat in a graduate class under Professor S. W. Parr at the University of Illinois and heard him foretell the early disappearance of the then common beehive coke oven and improvements in the manufacture of by-product coke with its attendant by-products. Those of you who went through the Connellsville district of Pennsylvania a few years ago must have marveled, as I did, at the great tongues of flame and smoke leaping out of the hundreds of little beehive coke ovens. Today these ovens are deserted and grass-grown. In their place, at Clairton on the Monongahela river, stands the great by-product coke plant of the U. S. Steel Corporation where is treated one per cent of the entire coal production of the world. Not only is the coke better than the old beehive coke, but in the by-products hundreds of chemicals are produced, ranging from road tar to aspirin. They are recovering from the coke oven gas, pure sulphur of such fineness that it finds a great demand among orchardists as the most effective method of destroying fungus and other tree diseases. They are saving sodium thiocyanite which has been found to hasten greatly the germination of potatoes; and many other new by-products. But in these things we invade the province of the chemist. Of the utmost interest to coal preparation, however, is the elusive field of preparing, from the raw coal, a smokeless fuel. Why we of the twentieth century continue to accept the present smoke nuisance of our towns and cities is unanswerable.

Certainly in a broad way we do not save money by present conditions. Nothing would popularize soft coal like making it smokeless and at the same time retaining its desirable burning qualities. No one has carried the work further than your own Professor Parr. The future, however, holds an unlimited opportunity to reduce research to practice in this field. It is not too much to prophesy in turn the introduction of a successor to the by-product oven which will entirely gasify the coal, thus completely converting coal to the ideal fuel without incidental production of coke.

Years ago the coal industry faced a crisis in competition from natural gas. Within a few years the natural gas resources near the large consuming centers were exhausted and coal again took command. Within the past three years the coal industry again faces this danger. Improvements in pipe manufacture and pipe line construction have made it possible to construct pipe lines for natural gas of a length and size hitherto considered impracticable. A natural-gas line has been finished recently from northern Louisiana to Atlanta, Georgia, and others ranging up to 900 miles in length are projected. To meet this competition is it not possible for the coal industry to pipe gas manufactured from coal over like distances, thus preparing the coal at the mine into gas, instead of shipping the coal? Already in New Haven, Connecticut, there is a coal-gas plant which supplies 65 per cent of all the gas used in the State and the gas is piped to Hartford, and other distant towns.

I am informed that at Clairton, Pennsylvania, the excess gas produced at the ovens at certain times of the year is pumped in great quantities down old exhausted natural gas wells near McKeesport. Later when this gas is withdrawn for use it is found to have changed in character, having lost some of its objectionable compounds and to have absorbed enough methane from the strata so that its heating value is considerably greater than when pumped into the ground.

Will the coal industry slow down until the peak of natural-gas competition is passed, or will it be able through discovery and technical skill to meet the competition by preparing a suitable competitive fuel? Certainly the natural-gas industry is showing us how to ship heat units to the markets as a lesser cost than hauling them on the railroads.

(3) *Coal as a base for new chemical industries.*—Most of you know that in Germany and France they have succeeded in taking raw coal and preparing from it directly by hydrogenation a liquid which can be used as a substitute for gasoline and fuel oil. With the high cost of gasoline there they are actually selling the liquid coal as an auto fuel. My own feeling is that within a decade, we may be using larger supplies of our own coal to produce a similar fuel here. At any rate the discovery destroys any fear of an automobile fuel shortage.

Altogether I feel that the great future work to be done in coal preparation will be to develop the use of coal as a base for new industries, especially the chemical industries.

It is an interesting fact that nearly all the research in coal up to the present has tended to restrict rather than increase its production. We are informed that the modern central power station using coal produces a kilowatt with one-half the coal that it did ten years ago and that improvements in locomotive design reduces by 30 per cent the coal necessary to haul a ton of freight a mile. In preparation of coal in the by-product ovens more coke is obtained than in the old beehive and with the resulting gas this means that for each unit of heat used, less coal is required. All of these advances, although of general benefit to the public, do not promote the use of more coal.

The time is here to begin to devote our research to ends that will increase the uses of coal. I am informed that today, in every telephone transmitter are grains of coal which help to change the current as your voice changes. Compared to the tonnage of coal which may be used by further discoveries and improvements in the chemical industries, the quantity of coal needed for telephone receivers is ridiculously small, yet in this whole field of finding new uses for that wonderful complex organic chemical substance we call coal, lies the future prosperity of the coal industry.

THE AUTOMATIC STOKER FOR HEATING SERVICE, USING ILLINOIS COAL

By A. C. Willard¹ and W. H. Severns²

INTRODUCTION

The development of automatic equipment and methods for heating buildings in the past few years has included practically every kind of fuel and type of burner. The final objectives in this development must provide for *economy* (including smokelessness), *comfort and convenience*. To entirely sacrifice the first of these objectives for the sake of the other two, is quite indefensible in any comprehensive and fundamental consideration of the problem. What is needed in the ultimate solution of this problem is automatic equipment which will burn the least expensive fuel in any locality with maximum efficiency and with practically as much comfort and convenience as can be secured with any other fuel, whether fired manually or automatically.

For the state of Illinois and much of the Midwest the least expensive fuel is the native bituminous coal. This fuel cannot be burned successfully in heating boilers and furnaces without smoke and with high efficiency by any method of hand firing unless more or less special equipment is installed. Moreover, even with special equipment installed, hand firing is inherently less convenient than any method of mechanical stoking. Mr. Victor J. Azbe³ has proved that the correct principle for complete combustion with bituminous coal is that the distilled volatile gases must pass through the hot fuel bed and then be mixed with the air to complete the combustion practically at the surface of the fuel bed. This principle is satisfied by the down-draft furnace, the down-draft baffle, and the underfeed stoker; only the last of which can be regarded as automatic, and hence, effective in promoting comfort and convenience.

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³ Azbe, Victor J., Smokeless and Efficient Firing of Domestic Furnaces, Parts I and II. Transactions of the American Society of Mechanical Engineers, Fuels and Steam Power Division, January-April, 1928, page 175, and September-December, 1928, page 223.

CHARACTERISTICS OF THE AUTOMATIC MECHANICAL COAL STOKER

The automatic mechanical coal stoker working on the underfeed principle will burn a less expensive fuel with greater economy (including smokelessness), and will at the same time provide fully as great comfort as can be secured with any other fuel fired automatically. It cannot be said that the stokers of the present day provide even approximately as much convenience as either oil or gas burners of the automatic type. They are, however, far more convenient to operate than any hand-fired heating unit, and the amount of attention which they require will be materially reduced as their development progresses. They satisfy the three objectives of *economy*, *comfort*, and *convenience* to a remarkable degree even in their present state of commercial development. For the central states of this country the less expensive fuels as already noted are the small sizes of Midwestern bituminous coals, which underlie much of this territory. These coals are relatively high in volatile matter, and if they are to be burned with the greatest efficiency, require careful combustion control. To secure such economy in combustion with the maximum of convenience and comfort the automatic mechanical underfeed stoker must be employed.

In the underfeed type of stoker, the volatilization takes place below the incandescent part of the fuel bed, and the unstable hydrocarbons are decomposed into fixed gases under the action of the hot carbon in the incandescent zone. This prevents the formation of smoke, which results from the partial combustion of the hydrocarbons in the presence of insufficient air at the surface of the fuel bed. A high temperature is maintained above the surface of the fuel bed, and the complete combustion of the fixed gases is accomplished by the admission of the proper amount of secondary air above the fire. The use of mechanical blowers with gates or orifices, instead of placing reliance on the uncertain relations existing between natural draft and the resistance of grates and fuel bed, permits very close control of the air required through the fuel bed. Since the amount of air forced through the fuel bed determines the rate of combustion, when stokers are used in connection with heating units the speed of the blower should be governed by the outdoor weather conditions, thus regulating the rate of combustion to correspond to the weather. The speed of the coal feeding mechanism should then be accommodated to the rate of combustion. The completeness of combustion is determined largely by the amount of secondary air admitted above the fuel bed, and in order to reduce the excess air to a minimum this amount should be regulated to correspond with the combustion rate. It should vary with the speed of the blower and the rate

of coal fed. As a rule, with proper operation, the loss due to combustible in the ash is small. Until it is fully appreciated that the proper control of an underfeed stoker depends on the correct regulation of both the primary and secondary air supply rather than on pounds of coal fed to the furnace, the operating adjustment of such a unit will be a matter of chance rather than intelligence.

The automatic mechanical stoker, moreover, is an apparatus requiring engineering knowledge rather than mechanical skill for its preliminary adjustment for proper combustion control. The advantages offered will, therefore, not be attained generally until the necessity for such knowledge is widely recognized, and until installations and adjustments are made under the competent direction of trained men instead of relying entirely on the services of skilled mechanics without the background of fundamental knowledge in the field of combustion. The mere presence of a stoker is not a guarantee of efficient performance and a poorly adjusted stoker may be no better than a manually operated plant.

PERFORMANCE TESTS OF AN AUTOMATIC STOKER AND STEAM HEATING BOILER UNIT

As an illustration of the performance of a modern stoker-boiler unit under actual operating conditions, such as exist in heating service using an inexpensive grade of Illinois bituminous coal, the following results (Table 4 and Fig. 9) from a series of tests just completed at the University of Illinois are presented. These tests are preliminary to a further and much more complete study of stoker-boiler unit performance.

The testing plant is shown (before boiler and pipe covering was applied) in figure 8. The boiler was a standard commercial welded steel firebox type with a double pass of fire tubes. The principal dimensions taken from manufacturer's data were:

Heating surface = 262 sq. ft. = 241 sq. ft. (using fire surface).

Grate surface = 11.6 sq. ft.

Ratio H.S./G.S. = 22.6.

Tubes all 3 in. outside diameter.

First pass 21 tubes 4 ft. 7 in. long.

Second pass 24 tubes 6 ft. 4 in. long.

Length of firebox = 70.0 in.

Width of firebox = 30.0 in.

Height of firebox = 26.0 in.

Volume of furnace and combustion chamber above grates, apx.

$20 + 10 = 30$ cu. ft.

Height water line = 69.0 in.

Smoke collar = 22 in. diameter.

Stack steel = 20 in. diameter and 44 ft. above grate.

Rating in sq. ft. of direct steam radiation of 240 B.t.u. value = 3630.

The stoker was also a standard commercial screw-feed type with separate motor drive for coal feed and fan. The coal feed could be regulated by hand control of motor speed, as well as by an on and off

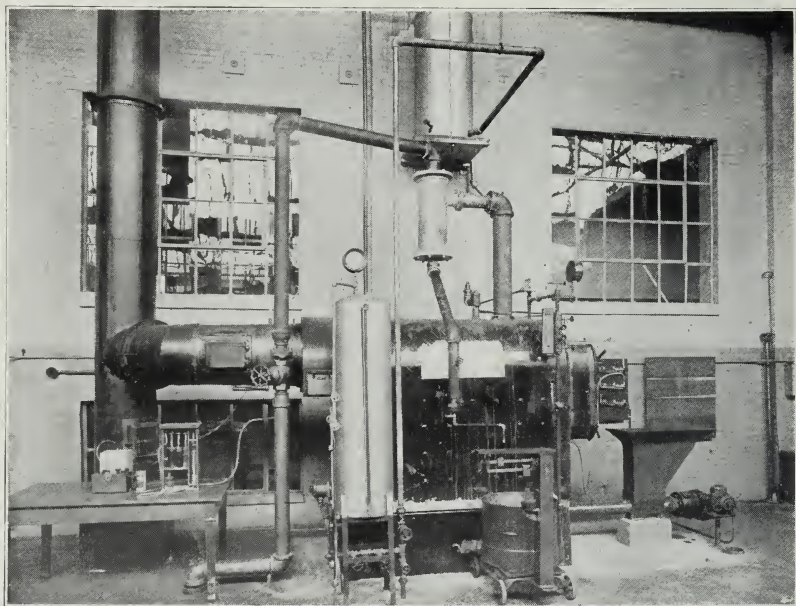


FIG. 8. Elevation view of stoker-boiler unit ready for test. (Picture taken before covering was applied to boiler, tanks and piping.)

pressure stat. The coal tube was 4 inches in diameter inside and the coal retort was 7 by 17 inches just below tuyeres. Coal screw $3\frac{3}{4}$ inches diameter maximum at entrance to retort and $2\frac{7}{8}$ inches diameter at hopper; driven by $\frac{1}{4}$ horsepower single phase brush shifting motor, 220 volts. Capacity at full speed approximately 150 pounds of coal per hour. Maximum wind box pressure, 3.2 inches, water gage and fan driven by $\frac{1}{2}$ horsepower single phase constant speed motor. The local power company supplies current for small stoker motors at 7 cents per kilowatt-hour.

The fuel used was $1\frac{1}{2}$ inch screenings of the analysis shown in Table 4, and cost \$3.60 per ton in the bin.

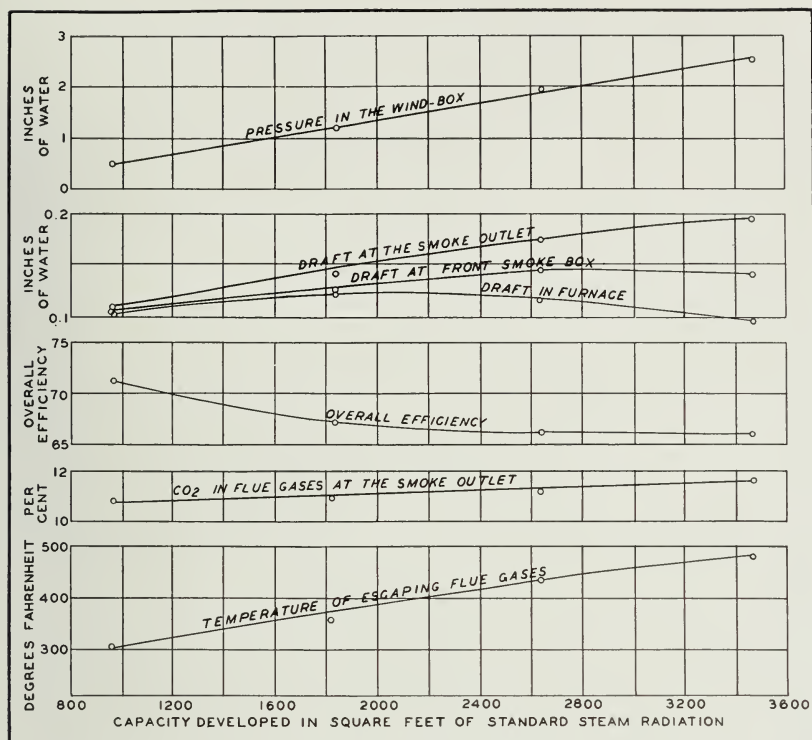


FIG. 9. Tests of a stoker-fired heating boiler at the University of Illinois, Urbana.

CONCLUSIONS

Based on the stoker-boiler unit tested, the results (Table 4) indicate that:

(1) A less expensive grade of Illinois coal (costing \$3.60 per ton in the bin) may be burned without visible smoke and with good efficiency, ranging from 65 to 70 per cent. In the opinion of the authors, the principal saving from the use of automatic coal stokers will result from the use of a less expensive fuel, burned efficiently and smokelessly.

(2) The stoker will perform automatically for considerable periods of time and maintain a practically constant steam pressure with a maximum variation of $\frac{3}{4}$ pound above or below normal.

(3) The attention required in heating service will depend on the weather conditions and the frequency with which the hopper must be refilled or the fire cleaned, at which time ash and clinker is also re-

moved. In severe weather, the attention must be more frequent than in mild weather.

(4) To what extent labor costs may be reduced by the installation of a stoker was not within the province of the present tests. It is certain, however, that a stoker will relieve the attendant for considerable periods of time, so that more stoker-fired plants may be operated by one man or he may have more time for other duties than with a hand-fired plant.

(5) It is rather difficult to so adjust both primary and secondary air that the coal feed and air supply will be perfectly synchronized. As a result of failure to synchronize the air supply and coal feed, either coal may accumulate gradually in the fire box or the fire may burn thin.

(6) The relative amounts of primary and secondary air must be varied with the rate at which coal is fed and better and more accurate air control devices or equipment are desirable if not essential.

(7) The rate at which coal is fed has very little connection with the rate of combustion in "on and off" operation. Only when the stoker runs continuously will rate of coal feed be the same as the rate of combustion.

(8) Average CO_2 readings and average flue gas temperatures mean very little in these tests with "on and off" operation even though "time on" and "time off" is accurately determined. Single CO_2 readings are of the greatest value, however, in adjusting the primary and secondary air to give best results with different coals or with different rates of feed of the same coal.

(9) It is practically impossible to make an accurate "heat balance" with a stoker operating on an "on and off" control. This can only be done when stoker operates nearly continuously, which means that at less than full load capacities the rate of coal feed must be reduced and the air supply readjusted accordingly to give continuous operation.

(10) Special consideration should be given to the undesirability of creating hopper smoke, especially with a nearly empty hopper and with more or less clinker in the furnace.

FUTURE INVESTIGATION OF STOKER-BOILER UNITS

(1) A carefully planned program of tests should be conducted to determine the best method of stoker control for heating service. At least two general methods deserve careful study.

One provides a constant, maximum rate of coal feed sufficient to take care of the full load requirements. In mild weather, this same rate of coal feed is used but the stoker is "off" a much greater proportion of the time. The air supply adjustment is kept constant.

The other method provides for a variable rate of coal feed with corresponding adjustment of the air supply. In mild weather, the lower rates of coal feed are used and the stoker is "on" about the same length of time regardless of the weather. This method would appear to be more efficient, but would demand more attention and skill on the part of the attendant.

(2) Two series of tests using different coals as well as different sizes of the same coal should be conducted to determine whether or not higher efficiencies might justify the use of somewhat more expensive coals. Material variations in heat value, volatile matter and ash content should be the basis for selecting these different coals, to give as wide a spread in coal characteristics as possible.

(3) Another series of tests should be undertaken to determine the effect and importance of furnace and combustion chamber space on stoker operation, at both high and low loads or rates of combustion. There is no doubt that the ratio of furnace and combustion chamber volume to pounds of coal burned per hour has an effect on both efficiency and capacity of a stoker-boiler unit.

TABLE 4

Department of Mechanical Engineering
University of Illinois

Mechanical Engineering Laboratory

RESULT SHEET

STEEL HEATING BOILER AND AUTOMATIC COAL STOKER

(For dimension data see text)

Also see Fig. 8 for elevation view of stoker-boiler unit as tested

No.	Name of Item (With Units)	Trial Number			
		1	2	3	4
1.	Date of test	April 17 1930	April 18 1930	April 22 1930	April 23 1930
2.	Duration of test, hrs.	6	7	8.25	9
3.	Kind of coal	Illinois Coal			
4.	Size of coal	1½-inch Screenings			
5.	Proximate analysis of coal as fired:				
	Fixed Carbon, per cent.	43.44	42.69	42.12	42.56
	Volatile Matter, per cent.	37.02	36.38	35.91	36.28
	Moisture, per cent.	7.10	8.70	9.89	8.98
	Ash, per cent.	12.44	12.23	12.08	12.18
	Sulphur, separately det.	4.42	4.35	4.29	4.33
6.	Calorific value of coal as fired by oxygen bomb calorimeter, B.t.u. per lb.	11,133	11,036	10,892	11,002

TABLE 4 (Continued)

No.	Name of Item (With Units)	Trial Number			
		1	2	3	4
7.	Calorific value dry coal, B.t.u. per lb.	12,088	12,088	12,088	12,088
8.	Ultimate analysis of coal as fired:				
	Carbon, per cent.	60.63	59.58	58.78	59.40
	Hydrogen, per cent.	4.62	4.53	4.48	4.52
	Oxygen, per cent.	8.73	8.58	8.47	8.56
	Nitrogen, per cent.	2.06	2.03	2.01	2.03
	Sulphur, per cent.	4.42	4.35	4.29	4.33
	Moisture, per cent.	7.10	8.70	9.89	8.98
	Ash, per cent.	12.44	12.23	12.08	12.18
9.	Steam pressure, lb. sq. in. gage.	3.14	2.76	2.83	3.2
10.	Barometer, in. Hg.	29.26	29.51	29.54	29.46
11.	Steam pressure, lb. sq. in. abs.	17.50	17.30	17.33	17.65
12.	Pressure in wind box, in. water	2.58	1.92	1.20	0.56
13.	Draft in furnace, in. water.	0.097	0.115	0.123	0.102
14.	Draft in front smoke box, in. water.	0.135	0.141	0.124	0.104
15.	Draft at smoke outlet, in. water.	0.196	0.179	0.143	0.106
16.	Temperature outside air, deg. F.	65.9	47.4	46.4	49.3
17.	Temperature air of room, deg. F.	85.7	81.0	75.5	77.5
18.	Temperature gases at smoke outlet, deg. F.	475	432	357	303
19.	Temperature steam leaving boiler, deg. F.	220.9	220.7	220.5	221.1
20.	Temperature feedwater at measuring tank, deg. F.	205.1	201.3	195.6	182.9
21.	Total inches of water fed.	737.63	647.75	525.62	296.92
22.	Total weight of water, lb.	5119	4502	3658	2078
23.	Total weight of water from separator, lb.	20	8.25	8.5	8.0
(Note that heat loss from separator accounts for about 0.9 lb. of condensate per hour.)					
24.	Quality of steam.	0.997	1.00	1.00	1.00
25.	Total factor of evaporation.	1.007	1.014	1.020	1.033
26.	Total equivalent evaporation, lb.	5154	4570	3733	2146
27.	Total weight of coal fired, lb.	683	610.5	494.5	268
28.	Total weight of ash and refuse, lb.	51.75	62.5	51.0	22.75
29.	Analysis of ash and refuse:				
	Moisture, per cent.	0.16	0.07	0.03	0.04
	Volatile matter, per cent.	0.00	0.00	0.00	0.00
	Fixed carbon, per cent.	7.86	4.46	5.15	3.19
	Earthy matter, per cent.	91.98	95.47	94.82	96.87
30.	Stoker in operation, time per cent.				
(Note stoker operated with "on and off" control for variable periods of time, and also stoker operated at variable rates of feed during the "on" periods, depending on operating load.)					
31.	Interval between raking fire, mins.	71.2	46.0	53.0	66
32.	Interval between cleaning fire, hours.	6	3.5	8	9
33.	Average height water in gage glass, in.	0.77	0.78	0.75	0.73
34.	Equiv. evap. per hour, lb.	859.1	653	453	238.5

TABLE 4 (Continued)

No.	Name of Item (With Units)	Trial Number			
		1	2	3	4
35.	Coal fired per hour, lb.	113.8	87.2	60.0	29.8
36.	Pounds of coal, per hour, per cu. ft. of furnace and combustion chamber volume.	3.79	2.90	2.00	0.99
37.	Equiv. evap. per sq. ft. of heating surface per hour, lb.	3.56	2.71	1.88	0.99
38.	Equiv. evap. per lb. of coal fired, lb.	7.55	7.49	7.55	8.07
39.	Capacity developed, sq. ft. rad.	3475	2643	1832	962
40.	Percentage of capacity developed.	95.7	72.8	50.4	26.5
41.	Efficiency of boiler with stoker, per cent.	65.9	66.0	67.3	71.2
42.	Flue gas analysis, stoker in operation:				
	(Note that with "on and off" operation of stoker <i>average</i> flue gas analyses mean very little. The CO ₂ values are given only for periods when the stoker was "on." In the last test, the CO ₂ for stoker "on" and "off" dropped to 8.1 per cent. Similar reductions were observed in the first three tests for "on" and "off" operation.)				
	Carbon dioxide, per cent.	11.5	11.1	10.8	10.8
	Oxygen, per cent.	7.3	8.4	9.1	9.1
	Carbon monoxide, per cent. ..	0.4	0.1	0.0	0.0
	Hydrogen, per cent.	0.15	0.1	0.0	0.0
	Nitrogen, per cent.	80.65	80.3	80.0	80.1
43.	Smoke data:				
	Periodic and regular observations of the smoker were not taken. In general, smoke of number 1 and 2 grade appeared only when the fire was disturbed or when the stoker cut into operation. For the major portion of the time of observations the stack was smokeless or very nearly smokeless.				
44.	Average kw. per hour to operate	0.433	0.51	0.357	0.21
	(Note smaller value in column 1 at full load is due to better position of motor brushes with motor operating at full speed.)				
45.	Cost per hour to operate stoker and fan unit at 7c per kw. hr., cents per hour.	3.0	3.6	2.5	1.5

Also see Fig. 9 for graphical log of test.

UTILIZATION OF BASIC INFORMATION IN FUTURE MARKET PRACTICE

By F. C. Honnold ¹

THE PRESENT MARKET SITUATION

None but those actively participating in the production, sale, transport and final distribution of Illinois coal are apt to realize the extent and variety of the embarrassment that confronts its operators and miners, or that of individuals and concerns who are or have been the consumers of Illinois coal. A very brief presentation of a few outstanding factors that have brought this condition about seems essential in order that what is said later on may be better understood.

THE COMPETITIVE SITUATION

The Chicago switching district is the largest coal-consuming center in the world. Forty per cent or more of the total railroad mileage of the United States centers there. As among all cities of first magnitude, it is also nearest the exact center of the country's manufacturing industry, agricultural production, and general population.

Because of these facts probably no like area anywhere in the country produces and ships either so much or so wide a variety of manufactured products as moves out of that section including Illinois, southern Wisconsin, the eastern half of Iowa and that part of Missouri north of a line from Kansas City to St. Louis. It is very easy to understand why competition among fuels of all kinds and from an extreme number of points of origin should exist constantly within this outlined territory, which constitutes the primary market for our coal.

LABOR

During the period from 1920 to the fall of 1928, the labor situation in the Illinois coal industry was at all times a *serious* handicap. Based on the present wage contract, expiring March 31st, 1932, our position would appear much improved and definitely more promising, although

¹ Secretary-Treasurer, Illinois Coal Bureau, Chicago, Illinois.

disturbing confusion still prevails. We are sincerely hopeful that labor may in the early future become and thereafter continue more dependable.

The experience of Illinois miners during recent years has made them realize that if they are to succeed, they must recognize and fully discharge their direct obligation to the public whom in reality they serve. They are now fully aware that constantly erratic and uncertain operation of Illinois mines, because of local and state-wide strikes, has hurt them as directly as anyone else, possibly more so. They also now know that the long continued demand for an impossible wage rate and restrictive operating practices made it increasingly difficult to a point of ultimate impossibility for Illinois coal to compete in the markets.

Their change of viewpoint can be understood when it is remembered that 87 cents of every dollar spent in the production of a ton of coal, at shaft mines, goes directly to labor, either in the form of wages, dues paid to their union, or amounts expended in their behalf under the Compensation Act. In few if any other industries does labor participate so directly in the sale price at the point of delivery of the raw commodity which they produce.

ILLINOIS COAL PRODUCING COMPANIES

Regardless of the fact that those operators producing and sending to the commercial market the larger volume of Illinois coal are already providing a very superior product, as to removal of impurities and careful preparation and sizing of their coal, they realize the importance of maintaining always the highest possible standards of practice in these, as well as in other, respects, in order that the quality of their coal may be maintained at a high level. To this they commit themselves and will in the future, as in the past, seek, through cooperation with their miners and by every means, to maintain a high standard and to be constantly on the lookout for new and better ways of discharging their function as dependable service agents, which in reality is an exact definition of their status. The bulk of the money paid by coal consumers—at the average destination where final delivery is made in car lots—goes to the miner for wages and to the railroads for freight. It is a very rare year when a producing coal company receives for its service as much as five cents out of each dollar paid by the ultimate destination car-lot buyer. Further, it should not be forgotten that an average of about 40 per cent of the total annual production at an Illinois mine fails to return even its cost. This applies to all coal passing through a two-inch, round, screen opening.

FREIGHT RATES AND TRANSPORTATION

Although this is not a subject to be dwelt upon in detail at a conference of this character, some brief mention of this important factor in the present situation is essential. (1) That the cost of coal transportation, considering an average of all destinations, exceeds the price paid for coal at the mine, should always be held carefully in mind. (2) The further coal is hauled, the higher its cost, and there are no heat units in a freight bill.

These two facts make clear that discriminatory or prejudicial rates as between producing fields may become destructive and produce disastrous results to the welfare of any state whose own coal production is substantial.

Illinois coal producers, Illinois miners, and a very large part if not a majority of the consumers of Illinois coal feel strongly that the changes and readjustments of freight rates affecting Illinois coal have since the war been inequitable and more or less unjust. At all events they have been the direct occasion of a very large loss of tonnage that might have moved from Illinois mines.

The grant (in 1924), under authorization of the Interstate Commerce Commission, of joint through rates, permitting a wide variety of eastern non-union coal to move to an extremely wide western destination area, extending well beyond the Mississippi river, might seem to be in very definite violation of economic propriety closely approaching a serious discrimination between coal producing states.

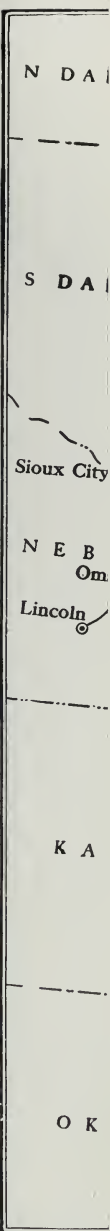
We shall not dwell longer on this subject because certain very important cases bearing on this precise situation, which we feel so seriously affects the welfare of Illinois, go to hearing early in June and will probably at that time be the subject of sufficient general publicity to advise all of those who are directly interested.

PRESENT SITUATION

The present situation in the Illinois coal industry is one of revolutionary, social and economic readjustment. Such a change always comes slowly. This is due to the fact that the great majority of the people do not take seriously and consequently know little about those larger economic questions that often so vitally affect their own immediate welfare.

Figure 10 portrays the geographic situation of the Illinois coal field with regard to lines of transportation and the country's centers of (1) manufacture, (2) population, and (3) agriculture.

There must be widespread reliable information that will stimulate intelligent public thought and careful consideration in and out of Illinois, with respect to possible serious future consequences that may de-



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Fig. 10
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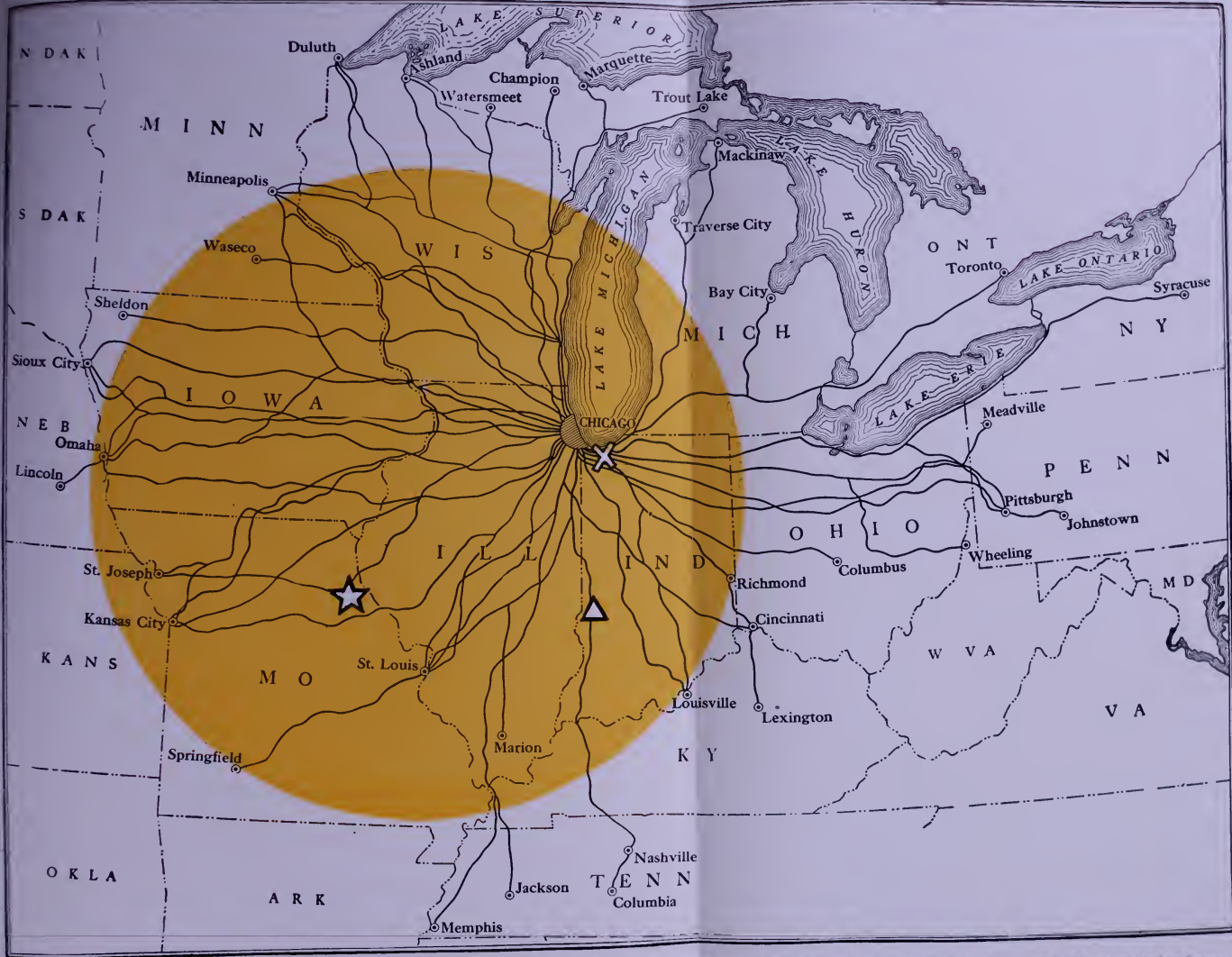


Fig. 10. The unmined coal reserves in the State of Illinois exceed that of any other state east of the Missouri River and there is enough to last hundreds of years. In the immediately adjoining states of Indiana, Illinois and Missouri are the country's center of manufacture, marked by a cross; the center of population, marked by a triangle; and the center of agriculture, marked by a star.

The strategic importance of this section is easily understood. That it will remain a focal point of great importance is certain. Passenger schedules on railroads entering Chicago enable more than 30,000,000 people to reach this midwest metropolis overnight and without the loss of working time.

The black lines represent railroads with such schedules reaching important cities.
Forty per cent of the Class 1 railroad mileage of the entire country centers in Chicago.

velop from present careless neglect of the welfare of the coal producing industry in Illinois. For our purposes we are perfectly willing to accept the estimate of Mr. Garcia as to the amount of the unmined coal reserves still available in our state. The area in which it is found (42,000 sq. miles) is larger than that in any other state. That this volume of coal is near by and accessible on short freight hauls to what will undoubtedly be the largest coal market and general trade area of the country for many years to come, guarantees a dependable fuel supply for a good many hundred years. This great treasure also can, when properly handled, and with very few exceptions, *do all that any fuel can do* and at substantially less cost. It is for those reasons by far the most valuable resource the state has. Coal gone cannot be replaced.

This near-by coal reserve deserves the protection of every mid-western consumer of this coal against every unwarranted competitive assault.

It is the settled belief of Illinois coal producers, following a very careful survey and study of all other competing coal producing districts, that in no other state, taken in its entirety and the average coal quality considered, has there been during so long a period such positive and definite elimination and restriction, both in the number of operating mines and the number of workmen thrown into idleness during the past decade.

Enough has been said here to adequately outline a present status and to suggest why we at this time urge so strongly the mutual participation and assistance of all parties concerned, as a simple matter of enlightened self interest.

FUTURE MARKET PRACTICE

With such prelude we come to the direct consideration of those things suggested by the published title of this paper, "Utilization of Basic Information in Future Market Practice." We list below twelve items on which we shall require continuing information and effort. These have not been set forth in the order of their importance since each of them will as to their importance vary from time to time, but each alike should have constant attention :

1. Labor.
2. Intelligent constructive activities by producing companies.
3. Transportation conditions, rates and other incidental factors.
4. Awakening education and fact data to direct coal users.
5. Smoke abatement.
6. Combustion engineers.
7. Increase of combustion engineer personnel and service.

8. Constant active effort by universities and technical high schools, through research, testing laboratories and shops, along practical lines.
9. Informative, instructive bulletins of direct appeal to home owners.
10. Close cooperation along all practical lines of community interest with the makers of all types and kinds of approved or promising coal burning equipment, consuming either large or small annual volume of Illinois coal.
11. Continued publicity by each of the above specified groups, as well as closely cooperative and synchronized effort between related groups.
12. An annual conference in which there should be effective participation of all midwestern interests for the purpose of making careful presentation, canvass, and to the maximum possible extent determination covering proved and demonstrated facts of the preceding year and outlining activities for the succeeding year. Elimination to the greatest possible extent of all friction as between such groups with the single purpose constantly held in mind that we all alike seek to promote and guarantee the efficient and economical use of Illinois coal to the greatest possible benefit and convenience of the men who mine and transport it, the local distributor and those who use it—all to the welfare of this midwestern section of the country which is our home, not forgetting that "where the home is the heart is" (or should be).

The first three of these listed subjects have already been sufficiently discussed, or if not, and having, after the fashion of a Congressman "leave to print," may be elaborated in a bulletin which we hope to have issued promptly. The next seven items are those in which the University of Illinois can be directly and indirectly very helpful, and in undertaking to cooperate in the work contemplated will be rendering a direct and highly important service to the public of Illinois, which supports this institution.

AWAKENING AND EDUCATION OF THE PUBLIC

Much effort through every possible agency can and should be made to inform the public intelligently and honestly of exact facts. A large part of humanity, possibly a majority, are inclined "to follow the leader." Numerous illustrations of this fact have gradually developed with respect to the use of Illinois coal. One of these was and still is a growing antagonism to the purchase of our coal because of the erratic operation of our mines, the causes of which have been previously men-

tioned. The long continued relatively high price of Illinois coal has been another factor.

The public is not concerned with the wage rates paid to Illinois union miners, or that on four different occasions Illinois wage contracts were negotiated by the government, reaching a maximum peak eighteen months after the armistice; nor that this post-war high wage rate was paid continuously for almost nine years thereafter. The last three years it was paid only in Illinois, almost every other unionized district having meanwhile entirely or in part abandoned or in some way divorced itself from the miners' union. Illinois laws deny its coal operators any such privilege.

Neither is the coal consuming public at all concerned, except as it is reflected in their coal cost, with the fact that freight rates have advanced very substantially and still remain to the great majority of destinations 75 per cent or more above pre-war levels.

Whatever the cause may be that raises the price of any commodity or article, there is an instant effort to economize or to substitute something else. Thus with the price on Illinois coal held for a long continued period above any previous price levels, and with the non-union sections of the country able promptly to reduce their mine production cost 50 to 75 cents or more per ton, the consuming public, regardless of the higher freight rate on eastern coal, grew more and more antagonistic to our Illinois product.

It was believed that regularity of Illinois mine operation could not be relied upon but that regular and prompt service could be provided from eastern coal producing districts. Many large coal consumers either did not desire to or could not store coal. They also felt, as a part of their grievance against the Illinois coal industry, that their being compelled to store large amounts of coal while mines were idle on account of strikes was unfair, unjust, and should not be tolerated. Meanwhile, railroad service becoming more and more adequate, it was figured that regular receipt of an adequate supply largely if not entirely justified their payment of additional transportation cost through and by which they could either eliminate or greatly reduce storage and incidentally register their dissatisfaction.

The general public of this midwest section should know and fully understand, each coal consumer for himself, the lack of justification for going abroad for his coal requirements and that, in "following the leader," he, as a consumer, as well as the community and state in which he lives, suffers a direct economic loss as a result of his lack of information or misapprehension of facts.

SMOKE ABATEMENT

Smoke abatement has been another very large factor, which in connection with public indifference, has made publicity and an educational program not only desirable but imperative. *There is a growing demand for the elimination of smoke. That Illinois coal shall be successfully and economically consumed and without making smoke, must and can be guaranteed.* It is because the coal from our state cannot in the ordinary practice of the great majority of consumers, be hand-fired without the development of smoke, that so large an increase in the volume of eastern coal has moved into this state during the past half dozen years.

After the fashion that distance lends enchantment, and that the cow will risk the laceration of her neck getting her head through the barbed wire to eat grass no better than that in her own pasture, the belief is very widely held that any or all eastern coals can in the same careless fashion of many years back be burned smokelessly. This is not the fact. There must be exercised as much selective care in the purchase of eastern coal with respect to its being smokeless or having exceptional heat value, low ash and low sulphur, as should be exercised in the purchase of coal from any other source.

To secure positive, certain value and permanent results in the way of maximum fuel economy, with need for less labor and permitting increased mechanical control and the elimination of smoke, every coal consumer should at once give careful consideration to the benefit he can derive from reconditioning his plant to secure such benefit. In the development of power or heat and where the factor of special use and requirement does not enter, there is no doubt that the nearby coals are the best fuel for the people in this midwest section. A majority of the larger steam coal users of Illinois have known this for many years. It is the smaller users whose requirements range from 10 to 200 tons a year who are not aware of this fact. A very large amount if not a majority of eastern coal moving into the Illinois and adjacent areas west, occasions many direct and indirect losses to consumers and to the communities into which it moves. Whenever and wherever a fuel consumer can replace or recondition his equipment for its proper combustion, Illinois coal will make possible a minimum saving of from 50 to 75 cents per ton as compared with any eastern coal. In addition such a consumer will have established fuel economy through the use of nearby, short-haul coal and will also have done his bit in the elimination of smoke.

Ashes and other non-combustibles present in all coal must be reckoned with, however or whatever coal or coke is burned. The number of people willing to provide necessary attention to meet and dispose of

this handicap of coal will outnumber those who prefer to burn high-cost smokeless fuels (gas, oil, anthracite and coke) by several hundred to one. It is logical to conclude, based on the natural desire to save money, that this larger percentage of people will not shrink from the use of nearby coal, even though it involves some attending effort, if through the use of small stokers they can eliminate smoke, be provided with automatic firing and some dependable form of heat control, with longer periods between firing and with the removal of ash made easy.

COMBUSTION ENGINEERS AND OTHER PERSONNEL

To accomplish anticipated results means we must have an increasing demand for the advice and service of combustion engineers. The new day for increasing successful and economical use of the mid-volatile coal of Illinois will require widespread diffusion to the public of certain simple but vital facts with respect to the proper and intelligent use of coal.

The American public must be shown. What they can see, and watch in action, most quickly engages and stimulates their thoughts and ultimate decisions. Those, therefore, who will read, must be provided written text. Those who do not or will not read must be shown by exhibitions or individual demonstrations.

It is for this reason, that with the development of automatically controlled, mechanical coal-feeding units, there will be required the earliest possible training by our universities and other competent agencies, of a rapidly increasing personnel. The genius who may devise an instrument or the earnest student who may discover a fact or principle, renders very high service to humanity but such benefits could never be brought finally to the public without the many thousands of people who constitute the well organized personnel of any industry exploiting such idea or device.

It also seems desirable that we shall to the greatest possible extent avoid the mistakes and errors that occurred to the very great detriment of the oil burner manufacturers when their devices were first offered.

It seems most desirable to project our work after the fashion of a clinic rather than an experiment. Experimentation after installation, at the expense of the public, should be to the greatest possible extent avoided.

THE TASK OF UNIVERSITIES AND TECHNICAL SCHOOLS

We must, therefore, at the outset, look to our universities, technical schools, research laboratories, operating exhibits, and other helpful

agencies for assistance towards the development of this required and adequate personnel. Technical research, other than previous findings already available, probably will be of least essential value to us in meeting our immediate needs. Such research should be of substantial value later on and on that account should be encouraged, but only after careful determination of objectives.

Extensive research and experimental plants have already proved quite definitely that many suggested and theoretical methods for the transformation and use of coal, as well as its cheaper transportation from point to point, are for future use, being impractical for present utilization because of extreme cost of installation and operation, except in very occasional instances.

Present developed information with respect to vital and essential combustion principles and general practices, together with a comforting number of engineers skilled along these lines, must be our first line of defense with an increasing personnel coming along, varying somewhat in the precise character of their training. Some of them must be recruited as rapidly as possible, particularly for early utilization as service men, through short courses both at our universities and technical high schools.

For this reason whatever attempts we shall make now should be prompt and definitely practical. They should contemplate the best possible utilization of Illinois raw coal, and facts along this line should be made available to the coal consuming public at the earliest possible moment. This means that our thought runs particularly to the present helpfulness of mechanical and combustion engineers, in and out of colleges, through their shops and testing laboratories, utilizing to the best advantage our present accumulated fact data on proved combustion practice and the maximum serviceability and economy of our own nearby coal, for the present in its raw state.

COOPERATION WITH MAKERS OF ALL TYPES AND KINDS OF APPROVED COAL BURNING EQUIPMENT

That this is important and desirable goes without saying. The producers of coal or other raw commodities are in very few instances in position financially or otherwise to provide other than delivery of product at their own plants. They cannot manufacture, install devices for use, or instruct directly as to proper utilization.

They can, however, and should cooperate with the above named intermediaries who stand between them and the ultimate consumer because each of them constitutes a very important service element and each should understand fully the problem of the other.

Many prospective stoker concerns, in undertaking to exploit what seems to them "the last word" in the way of mechanical sufficiency, often will find later on that they did not fully understand or anticipate the difficulties to be met, in design, in finance, or in salesmanship and after more or less brief struggle, will be eliminated by the competition of more effective units. With proper cooperative arrangement, every individual or concern contemplating the exploitation of any device might be assured an opportunity of having his offering carefully studied and considered by neutral counsel who will have no competitive reason for neglecting or failing to recognize any merit his proposed enterprise may possess. If worth while, what he offers will receive its due share of recommendation and if unworthy or inadequate, he will from such counsel probably be protected against unnecessary loss. In either event, the public will be greatly benefited.

PUBLICITY TO BE SYNCHRONIZED

Publicity is such a widely diversified and highly specialized factor in business that any attempt to discuss its various ramifications as they might apply to the welfare of the various groups herein concerned, is not only folly but impossible.

The single thought here presented for careful consideration is the very great desirability of synchronization of thought, that all statements made shall be facts, on which policy alone the publicity of all of us will be solidly based.

There is a constant recurring tendency to overstate facts and to guarantee beyond proved possibility to perform. Such a procedure is very apt to bring about early failure which not only eliminates the offending individual but prejudices an entire enterprise such as that upon which we now are embarking. There are ample proved certainties as to what can be done with Illinois coal, used in a properly designed and serviced, mechanically-fired device, to fully justify the public adoption of such new methods for the use of nearby coal. Those, therefore, who seek to accelerate sale by exaggeration or by vague and unwarrantable statements, become at once an outstanding menace, hence the suggestion of synchronization.

ANNUAL CONFERENCES

There can be little amplification of what has been previously stated. A properly conducted conference can be made very inspiring and of definite potential value. There are many who work painstakingly, alone and with great care, stimulated by the hope that they may learn some

new fact or discover some new device or method that will benefit the public through some industry and its allied crafts. They labor with a germinating idea and possibly carry their findings to kindred spirits for incidental counsel, advice and suggestions until finally something definitely worth while, even if not perfect, is evolved. Periodic conferences where their several offerings of partial or total accomplishment may be submitted for discussion by or approval of their equals, naturally result in advancement in all lines of work and it is thus that our country as a whole has made such giant strides in the advancement of its general welfare, with an increased feeling of security, comfort, contentment and greatly enlarged enrichment of life.

THE CHEMISTRY OF ILLINOIS COAL

A Review and a Forecast

By S. W. Parr ¹

Without question, the boundary of the State of Illinois circumscribes the greatest coal deposit in the world.

By way of very brief retrospect, it is appropriate that a few mile-stones or "high spots" along the way be pointed out.

First—and without elaboration, for it needs none, let us quote from the first paragraph of the admirable bulletin by A. Bement ² as follows:

"It was in Illinois that the first recorded discovery of coal was made on the North American continent."

Second—from the bulletins and publications of the Survey, and also from the estimates contained in the Report of the 12th International Geological Congress—Canada, 1913—it may be seen that this Illinois area, extending slightly over into Indiana and into Western Kentucky, exceeds nearly three times the total area of all Europe, including that of the British Isles, and further, that the tonnage reserve credited to this Illinois area exceeds by one-third the total tonnage credited to Pennsylvania and West Virginia, combined.

Third—no serious study of a chemical nature had been made on the coals of Illinois previous to the year 1904. A small amount of chemical information was in existence previous to that date but it was entirely analytical in character and gave no information other than to tell the percentage of moisture, ash, volatile matter, fixed carbon and sulphur present in the coal. It is true that W. D. Rudy, a senior student in chemistry at the University, collected face samples from mines at Bloomington, Carbondale, Duquoin, and Mt. Carbon, Jackson County, upon which, as a topic for his Bachelor's Thesis, he made ultimate analyses, but, so far as the record goes, the purpose of the study was completed when percentage values for the elemental constituents were obtained.

It will be seen, therefore, that up to almost exactly twenty-five years ago there had been no investigational work whatever done on Illinois coals. You will see from this somewhat sweeping statement, that

¹ Professor Emeritus of Applied Chemistry, University of Illinois, Urbana.

² Bement, A., Illinois Coal. Illinois State Geol. Survey Bull. 56, 1929.

I have relegated purely analytical processes and results to a place outside the realm of investigation. This is true in the main, for analytical values for the most part are required as operating data by the engineer, who must know the percentage of combustible and non-combustible material, such as ash and moisture, which is delivered to him for the production of power. It does not apply, however, to investigations seeking to improve and make more accurate the processes of analysis.

So, I still maintain that the securing of data by chemical analysis is not chemical research on coal.

I recall, at this time, with no little interest, a conversation with Professor Breckenridge, Dean of the College of Engineering, the date being a little over twenty-five years ago. He said, in effect:

"Let us assemble all the known analytical data on Illinois Coals, from whatever source, which seems to be reliable, publish the same, putting it all behind us, then begin on a new and clean slate."

I think neither of us quite realized the significance of that program. As a matter of fact it marked the line of differentiation between purely analytical processes for furnishing operating data on the one hand, and on the other, the intensive study of fundamental problems relating to the constitution of coal, which was inaugurated soon after the organization of the Illinois State Geological Survey.

As evidence that this program proposed by Professor Breckenridge was adhered to, let me call your attention to the first published report on Illinois coal, which contained all of the analytical data available at the time. It was published under the title of "The Chemical Analysis and Heating Value of Illinois Coal," and, because of lack of funds or more correctly speaking, for lack of any definitely organized body formally backing such activity, the report was obliged to be published outside of the University. This was accomplished through the courtesy of the Illinois Bureau of Labor Statistics, the material being published as part of their report for 1902, a thousand reprints being supplied as "separates" for use of the University departments interested.

Fourth—as a fourth observation of a retrospective type, I desire to note the fact that, beginning with the year 1904, coal studies of a chemical nature were inaugurated which had an altogether different objective, seeking to develop information of a fundamental sort whereby a better understanding could be had of the properties, the behavior, and the functioning under all circumstances, of coal, leading also, ultimately, to a knowledge of the constitution of this very complex material, and that in a way which could not even remotely be furnished by the usual analytical processes.

In that year, a chemical study of Illinois coals was prepared for

distribution through the Illinois Exhibit, at the St. Louis Exposition. This was also published as the University of Illinois Studies, No. 7. This study, in addition to recounting some improvements in analytical methods, made special reference to an attempt to determine the behavior of sulphur in the process of coal decomposition by heat and also gave a very considerable account of new methods proposed for the determination of calorific values.

At this same date, 1904, there was inaugurated at the St. Louis Exposition an elaborate study, chiefly of an analytical nature, of all American coals, seeking an improvement and standardization of methods of analysis, and from this beginning, inaugurated under the auspices of the U. S. Geological Survey, has developed the mass of analytical and investigational data which has given the work of this sort a paramount place in coal studies throughout the world.

Fifth—I would like to recount some of the things which have been accomplished, chemically speaking, in connection with Illinois coals in the last twenty-five years.

Take the matter of classification; so early as the year 1907 a system of classification was worked out which not only indicates the correct location or rank of Illinois coals, in their relation to all other types but by means of it a definite index is obtained whereby coals of the State can be identified or located almost by counties, at least by districts, where the various sub-types may be found. This was a direct outgrowth of some of the early studies under the new organization of the Survey, which sought to draw a more exact line of demarkation between the inert or ash constituent and the organic or true combustible material.

From these studies, grew up the use of the term, "Unit Coal," which is the basis of our system of classification.

Again, one of the early studies was directed toward the peculiar and at the time little known phenomenon of oxygen absorption on the part of freshly mined coal. From these studies has grown a real understanding of the causes which promote spontaneous combustion, and following such information has come about a thoroughly practical and widely used system of storage of Illinois coal. This has involved also fairly complete information regarding weathering and deterioration as it occurs under storage conditions.

This matter of oxygen absorption is also a factor of fundamental importance in the carbonization of coals of the Illinois type, and by following along the lines thus indicated, an effective system has been worked out for coking these coals.

In this same connection, other studies for isolating and studying the properties of the bonding or agglutinating constituents have been

pursued, studies on the softening temperatures and the effect on that phenomenon of absorbed oxygen, studies on sulphur and methods for measuring its distribution as pyritic or inorganic combinations.

This list might be considerably extended, but enough has been given to show something of the scope and the type of the work undertaken. In general, it might be said that the work has been directed toward an understanding of the constitution of Illinois coal, and the inherent and specific properties of the type material of which the coal is composed.

The question now arises—what are the developments to be immediately ahead, and have these factors of the past twenty-five years furnished any help to the requirements, especially of an everyday and industrial sort for meeting the immediate needs of the future?

In the first place, it will be well to emphasize the necessity for investigational work.

It is difficult to understand why this need has not been recognized in the past, and it is certainly a crucial question for the future. I am sure we do not adequately estimate the relative value and importance of the coal resources of the State. The annual sale value, at least, to the ultimate consumer, is approximately one-quarter billion dollars. If we credit the agricultural product at 10 dollars per year, for every acre of area in the State, the value will be about the same as that given to the annual coal yield. Now, the total sum spent on agricultural investigations up to the present time can only be measured in terms of millions of dollars. By contrast, the total amount spent on *coal investigations* up to the present time amounts to just about thirty cents.

Of course, I am speaking in somewhat figurative but, I believe, relatively accurate terms and, especially would I not wish to be understood as criticizing the expenditure for agricultural research. The results in that field amply justify the expenditure, and difficult as are the agricultural problems today, it is sufficient answer to criticisms directed toward agricultural investigations, to ask what the present-day status of agriculture would be without that help. In fact, the dominant need of the day, in every line of activity, is for *research* to meet the competitive results of other research, and the coal industry is no exception to the rule.

Now the tendency on the part of every industry is to see only its own problems and perplexities, but the unraveling of a problem is not necessarily research. Its solution however may be possible, or of permanent rather than temporary value only if the fundamental factors are at hand for application to its solution. My plea therefore is that the coal industry make this distinction, and have an adequate appreciation of the value and need of that kind of investigational work as shall develop fundamental facts, whether their immediate value can be seen

or not. It is all very well to inaugurate a sales-propaganda to "buy more Illinois coal," but that gives only a temporary and evanescent relief. If the industry can see its ultimate salvation only in a slogan, I have one at hand, ready-made, namely, "Say it with flowers."

No, the need is more fundamental and involved, and requires a viewpoint for its solution which may be far removed from the pit mouth and the market.

Nor is it strange if these facts do not come into the range of vision of the coal operator. He has enough to occupy his attention in connection with fixed charges and labor costs, with market conditions and balance sheets. He can understand, of course, a straight red line drawn from Kansas City to Chicago, and marked as a proposed pipe line for natural gas but he has no data, or only a vague conception of how that fuel competition may affect or may be met by the coal industry.

It is obvious that about all that can be done at the present time is to state the problem. I have tried to indicate what the character of its solution should be. The sky is not all over-cast, there are a number of bright spots coming into view. I must say, however, that you must look outside of Illinois to see them; such gleams of hope, for example, as come from the U. S. Bureau of Mines, The Battelle Institute for Metallurgical and Fuel Research, the International Conferences on Bituminous Coal held at Pittsburgh, and we must also mention the numerous bureaus supported partly by public funds and partly by the coal interests, in England, Germany and France.

Users do not all require their fuel in the gaseous form nor all in the solid form, but all are more or less insistent that it shall be in better form, with less of dirt and grime, with more freedom from smoke and ash and sulphur, and with more care and attention. The old-time operator may have said, "I am mining coal for the one purpose of selling coal." But the future operator will be obliged to say, "I am mining fuel, and I find that fuel must be supplied to the public in the form which they require, regardless of my own wishes in the matter."

But, whatever the form, it is my conviction that the Illinois Coal Operator has it, potentially, in better form, or by subsidiary operations, can have it, and that his ultimate goal should be and doubtless will be, the mining out of the ground of more nearly 100 per cent of the precious fuel deposit there entrusted to his development, and bringing it to the ultimate user in some form which will always grade as No. 1, and that, with the absolutely ultimate essential of a profit.

RECENTLY DEVELOPED METHODS OF RESEARCH IN THE CONSTITUTION OF COAL AND THEIR APPLICATION TO ILLINOIS COALS ¹

By Reinhardt Thiessen ²

INTRODUCTION

During the last few decades, considerable advance has been made in the study of the origin, constitution, and structure of coal, so that these phases are well known. We are now entering on a new phase of coal research in which, besides endeavoring to pry into the chemistry of coal, the structure and constitution of coal are being correlated with its behavior under different uses.

The United States Bureau of Mines ³ is undertaking a chemical and physical survey of American coals so as to collect data concerning the behavior and suitability of coals under various conditions and uses. There is a considerable number of types of coal, each of which may be suitable for a special purpose or a better purpose than for that now used. The selection of these types of coal for the purposes for which they are best suited requires a knowledge of their composition and physical and chemical natures. A more complete knowledge depends further on the elucidation of the constituents or ingredients of which coals are composed, and the relative proportions in which they build up a coal.

COMPOSITION OF COAL

To make this clear, a brief review of the structure of coal, as it is now known, is necessary.⁴ Coals are composed essentially of two visibly different classes of constituents, anthraxylon and attritus (Fig. 11).

¹ Published by permission of the Director, U. S. Bureau of Mines. (Not subject to copyright.)

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³ Fieldner, A. C., Davis, J. D., Reynolds, D. A., Determination of Gas-, Coke-, and By-Product Making Properties of American Coals. Read at Atlanta, Georgia, meeting of the Amer. Chem. Soc., April, 1930.

⁴ Thiessen, R., Compilation and Composition of Bituminous Coals. Jour. Geol., vol. 28, pp. 185-209, 1920.

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ANTHRAXYLON

Anthraxylon comprises those constituents in coal derived from the woody tissues of plants, such as stems, limbs, branches, twigs, roots, including both wood and cortex, changed and broken up in fragments of greatly varying sizes through biological decomposition and weathering during the peat stage, and later flattened and transformed into coal through the coalification processes, but still present as definite unit constituents. With the naked eye they appear as homogeneous black bands, strips, or lenticular inclusions, generally of a bright outward appearance, varying in thickness from a fraction of a millimeter to several centimeters (Fig. 11). In general, they have a smooth black to a highly lustrous appearance according to the rank of coal—the higher the rank the higher the gloss. In thin section under the microscope these bands invariably reveal some of the original plant structure. This may be well preserved, or it may be recognized with difficulty, with all degrees of preservation between these two extremes (Fig. 12).

In the living and sound condition, wood is composed essentially of lignocellulose, which is cellulose and lignin. With these are associated a number of other substances, mostly pentosans in smaller amounts. It has been found that when wood is left in a favorable condition for rotting, the cellulose and pentosans are readily decomposed, but the lignin generally remains and in some way is converted into that substance termed humus or humins. Samples of woody peat are found to have lost most of the original cellulose and pentosans, but they have lost little of the lignin. When such samples are examined with respect to the age of the deposit, in other words, in a profile from top to bottom, it is found that although near the surface, as a whole, a considerable amount of cellulose is still present, it decreases toward the bottom, where there are merely traces or none.⁵ From this and other criteria it is deduced that the anthraxylon in all the coals is largely derived from the lignin of the plants. Unfortunately, the chemistry of lignin is not understood.

The woods of recent plants vary greatly in the ease in which they are attacked by micro-organisms, also in the ease in which they are macerated, so that the final products of decomposition and sizes of fragments resulting differ in many respects. For that reason the anthraxylon units in coal vary in similar respects.

It is mainly the anthraxylon that possesses the coking properties, and it chiefly lends these properties to the coal as a whole.

⁵ Thiessen, R., and Johnson, R. C., *An Analysis of a Peat Profile*. Ind. and Eng. Chem., Analytical Edition, Vol. 1, pp. 216-220, Oct. 15, 1929.

ATTRITUS

The attritus is that component in coal derived from any and all plant matter contributed to the deposit during the peat stage, macerated and comminuted through the agencies of micro-organisms, lower forms of animal life, and meteorological agencies, and subsequently consolidated and changed into coal. The attritus, therefore, contains much of the more and most resistant plant products. It is much duller in appearance than the anthraxylon, being usually of a dull gray color and of a striped appearance when intercalated with fine sheets of anthraxylon (Fig. 11). The attritus is the continuous fundamental matter, the disperse medium, in which the anthraxylon is embedded.

When thin sections are prepared from a coal and examined under the microscope at a low magnification, the attritus appears as a granular grayish mass lodged between the more homogeneous dark red bands of anthraxylon (Fig. 28). At a higher magnification—at 200 diameters and more—it is shown to consist of a number of different ingredients. Figure 13 represents a typical transparent attritus, and the following ingredients may be recognized in it:

1. Humic degradation matter
2. Opaque matter
3. Resinous matter
4. Fats, oils, waxes
5. Charred matter
6. Mineral matter

Besides these,

7. Cuticles are also found in all coals, and
8. Oil algae in some coals.

These ingredients have been studied in peat and traced through all the ranks of coals, so that their history is fairly well known.

HUMIC DEGRADATION MATTER

It is not easy to define what is to be understood by the term "humic degradation matter." When considered as to origin, a number of classes are distinguishable and shown to be derived from the following:

- a. Cell walls of woody tissues
- b. Cell walls of cortex, pith, bark, cork
- c. Leaf-parenchyma, wood-parenchyma
- d. Certain cell contents such as gums, starch, tannins, phlobaphenes, opaque matter
- e. Mosses, lichens, liverworts

In peat, particularly in the younger stages, these different classes may be distinguished from one another; but in the higher coals this can only be done with great difficulty or not at all, and so it is more convenient to combine them under the one term "humic matter." In well-matured peat, and in coal after it has been oxidized, they are soluble in alkalies forming a dark brown, colloidal solution, appearing black in concentrated solutions.

The humic degradation matter in coal is therefore largely but not altogether derived from the woody tissues of plants, and like the anthraxylon is largely derived from the lignin. The pure humic degradation matter possesses many of the properties of anthraxylon (Fig. 18).

SPORE-EXINES

Spores are the asexual reproductive organs of the lower plants, such as liverworts, mosses, and ferns. The microscopic spherical bodies consist of the inner living or protoplasmic parts surrounded by a thin membrane, the entine, which is enclosed in an outer relatively thick shell or membrane, the exine. This is composed of a number of resistant substances, such as cutin, esters of higher fatty acids, oils, and resins. All of these are very resistant to chemical reagents, oxidation, and micro-organisms. Because of this resistant nature, while the inner parts are decomposed the exines remain unattacked in relatively large numbers and always form an appreciable part of many coals.

Spore-exines are the most conspicuous constituents in coal, readily seen on account of their clear yellow color and transparency. They are merely the shells or outer walls or coverings of spores of the coal-forming plants, such as calamites, lepidodendrons, sigillaria, and sphenophylls. They may be recognized in the photographs as small linear patches. At high magnification their true nature is more clearly shown, and in cross-section they appear, when whole, as collapsed rings, often bearing wings or appendages. In reality, they represent collapsed spheres. Their contents have completely or almost completely disappeared. When seen in horizontal sections where they are shown on the broad side, they appear as circular to oval and sometimes slightly triangular discs. At high magnification they reveal many forms of sculpturings, tetrasporic markings, and hair-like appendages (Fig. 14).

There are many different kinds and sizes of spores in coals, and two kinds are recognized with respect to size—megaspores and microspores. From a biological standpoint these also differ in function.

The thickness of the spore-wall varies greatly with the kind of spore from which it was derived, and ranges from the tiniest film to huge, massive megaspores, easily visible to the naked eye.

Pollen-exines resemble spore-exines in general appearance and chemistry, but they are always relatively small and very thin.

It has been shown that the spores in coal, cannel coals, and oil-shales are the oil-yielding constituents. A coal, a cannel coal, or an oil-shale rich in spores is invariably also rich in oils.

CUTICLES

All leaves, fruits, and green stems of the higher plants are covered with cuticles to protect them from insects, bacteria, fungi, weather, and other injuries. These are often covered with a layer of wax in the form of a film, as hair-like processes, or as granules. In thin sections they appear as bright, golden-yellow bands, often found in pairs and commonly having serrated borders. The substances forming the cuticles are similar in chemical composition to those of spore-exines, and like them are very resistant to decay and chemical reactions, and for that reason are common objects in coal.

The chemistry of cuticles found in coal has been worked out in the laboratories of the British Safety in Mines Research Board and appears to be similar to that of the spore-exines in coal. On destructive distillation they were shown to yield 11 per cent saturated hydrocarbons, 22 per cent unsaturated hydrocarbons, 22 per cent aromatic hydrocarbons, 22 per cent oxygenated compounds, 11 per cent ether-soluble resin, and 11 per cent chloroform-soluble pitch.

RESINS

A large number of plants, such as the conifers, contain a considerable amount of resinous matter stored up in resin ducts, reservoirs, and fissures found in the wood, bark, and leaves. The chemistry of the resins of living plants is remarkably well known. The amount of these resins varies from a fraction of 1 per cent to as high as 10 per cent of the dry weight of the plant. In the lignites it is easy to find the resinous matters still intact in the anthraxylon and other tissues, exactly where they would be expected to be found. They are also found abundantly in the attritus of the lignites; the wood or other tissues simply decayed while the resins remained behind undecomposed (Fig. 20). The identity of the resins in the lignites is therefore certain. In the bituminous coals, resinous-appearing inclusions are also found in the woody tissues; these, it is safe to assume, are also remains of the resinous substances. In the attritus of the bituminous coals, resinous-appearing globules and particles are also frequently found and sometimes form a considerable part of it (Fig. 15). By analogy it is assumed that they are derived from the natural resins of certain plants.

In thin sections these resinous particles appear as spherical to oval globules of greatly varying sizes and of a dark yellowish-red color.

The products of distillation have as yet not been determined and still offer a field for investigation.

OPAQUE MATTER

The origin of the opaque matter in coal has as yet not been determined. Some indications show that it is derived from cell contents of certain plants. Its chemical behavior is similar to that of the humic matter described above, and like it may be dissolved in alkali after oxidation reactions, and so it must be classed with it. When concentrated or predominant in the attritus of a coal, either in certain layers or in the whole bed, it forms the underlying principle of a splint coal (Fig. 22). The opaque matter does not possess good coking properties; in fact, it inhibits coking when present in large amounts.

THE COMPILATION OF COALS

All of the ingredients named except the oil algae are always present in the attritus of ordinary coals. As a rule, the humic degradation matter furnishes the larger proportions, but any one, or occasionally any two may predominate, and thus determine its nature and therefore to a large extent the nature of the coal.

The relative amount and the nature of these ingredients determine the nature of a coal and form the basis of classification into types.

With respect to the presence or absence of anthraxylon, coals may be divided into two great groups, (A) those composed of both anthraxylon and attritus, and (B) those composed entirely or almost entirely of attritus.

A. COALS COMPOSED OF BOTH ANTHRAXYLON AND ATTRITUS

Coals which are composed of both anthraxylon and attritus in varying proportions are the banded or striped coals (Figs. 11, 16, 26, and 30). The two components may be found in all proportions, regardless of the nature of the one or the other, and according to the predominance of the one or the other determines to a large extent the nature of a coal.

(a.) A coal may be composed largely of anthraxylous or woody matter, forming anthraxylous coals (Figs. 16 and 17). These are characteristic in nature, very fragile, and have better coking properties than attrital coals of the same rank. There are a number of coals of this type. Coal of the lower bench of the Upper Freeport bed and coals of the No. 6 bed (Figs. 16 and 17) are good examples.

(b.) A coal may be composed largely of attrital matter. These also are characteristic coals. The Elkhorn coal is a good example (Figs.

30, 31, and 32). Between these two extremes all inter-grades of proportions of anthraxylon and attritus may be found.

The anthraxylon again may be present largely, (a) as relatively thick and massive units as in Figure 16, (b) all as relatively thin units as in Figure 26, and (c) all possible sizes generally mixed.

The anthraxylon may further vary due to origin, initial decay, and the physical nature, color, and cell contents of the original wood.

THE ATTRITUS

The various ingredients of the attritus itself may be present in varying concentrations in different coals. They may all be present in more or less equal proportions, or any one of them may be entirely or largely absent, but never is one found alone; or any one or two or three may predominate. This is true particularly of the attrital coals. The following types may be distinguished:

(a.) *Humic coals*.—The attritus may be composed predominantly of transparent humic degradation matter. There are a number of coals of this type. The Redstone coal is a good example (Fig. 18).

(b.) *Spore coals*.—The attritus may contain a large amount of spore matter together with a certain amount of transparent attritus. There are a number of coals of this type. The Pittsburgh coal, and a coal from the Barren Measures, McLeansboro Formation, and certain layers in the Elkhorn coal of Illinois, are good examples (Fig. 19).

(c.) *Resinous coal*.—The attritus may contain a large proportion of resinous matter. Coals of this type are found more often among the younger coals. A coal from Sunnyside, Utah, is an example (Fig. 20).

(d.) *Paper coals*.—Cuticular matter may be prominent. A coal from Malowka, Russia, known as *Papierkohle*, is a good example. Certain layers in a number of coals are composed largely of cuticular matter.

(e.) *Splint coal*.—The attritus may be composed predominantly of opaque matter. As a rule, a large amount of spore matter is associated with it, but not necessarily so. The anthraxylon in this type generally consists of thin irregular sheets, sometimes but sparingly present (Fig. 21). The attritus of this nature imparts characteristic features to this type, and is called splint coal in America, Mattkohle in Germany, durain in England. Whole beds, or merely certain layers of varying thickness in a bed, may consist of this type (Figs. 21 and 22).

Splint coals are quite different from other coals and are easily distinguishable from them, particularly in thin sections under the microscope (Fig. 22). They are irregular and lumpy, irregular or rough in fracture, grayish black in color, and of a granular consistency (Fig. 21).

LUCID-ATTRITE AND OPAQUE-ATTRITE

The types just characterized belong to the banded or striped coals. It will be seen that they may be separated into two distinct groups with respect to the nature of the attritus. The attritus of the one is distinctly transparent in thin sections, and may be called lucid-attrite; that of the other is quite opaque, rendered only translucent and partly transparent in very thin sections, and may be called the opaque-attrite.

We have, therefore, one type of coal composed of anthraxylon, in varying proportions and of varying thicknesses, associated with transparent attritus or lucid-attrite. These are the ordinary coals often referred to as "humus" coals. The other type is composed of anthraxylon, of varying proportions and of varying thicknesses, but generally smaller proportions and of relative thinness, and associated with an opaque attritus or opaque-attrite. These coals are the splint coals, Mattkohle, and durain.

B. COALS COMPOSED OF ATTRITUS

Coals composed entirely or almost entirely of attrital matter, or those in which anthraxylon is entirely or almost absent, are the cannel coals. Three main types of cannel coals are recognized:

- (a.) Spore cannel coals, in which spores form the chief ingredients (Figs. 23 and 24).
- (b.) Humic or pseudo-cannel coals, in which humic matter is the chief ingredient.
- (c.) Boghead coals, in which oil algae form the chief ingredient (Fig. 25).

All of these may be intermixed, forming sub-types.

FUSAIN

Fusain, mineral charcoal, or mother of coal is found in all coals, generally in relatively small proportions, although occasionally layers are found containing considerable amounts. Its origin and formation is a much debated question upon which there is no agreement.

This constituent is so well known that it requires no description at this time, but it may be pointed out that, although not all, most of the fusain is derived from woody tissue of which the structure is often well preserved. It is higher in carbon and lower in volatile matter than the other components, and has no coking properties.

When present in small proportions it has no marked effect upon the coal with which it is found, but when present in high concentrations, more than 20 per cent, it inhibits coking properties.⁶

TYPES OF COALS

A number of specific types of coal are therefore recognized and are broadly distinguishable, as follows:

1. Banded coals

- (a.) Anthraxylous coals.
- (b.) Anthraxylous and attrital coals in more equal proportions.
- (c.) Attrital coals.
- (d.) Splint coals (opaque-attrital).
- (e.) Humic-coals (lucid-attrital).
- (f.) Spore-coals.
- (g.) Humic-spore and spore-humic coals.

2. Cannel coals

- (a.) Spore-cannel coals.
- (b.) Pseudo- or humic-cannel coals.
- (c.) Boghead or algal-cannel coals.

Also,

- (d.) Spore-humic cannel coals.
- (e.) Spore-opaque-attrital cannel coals.
- (f.) Spore-boghead coals.

PROPERTIES OF COALS

Theoretically, a coal composed largely of anthraxylous matter should differ in behavior in its uses from an attrital coal; a lucid-attrital coal should differ from an opaque-attrital. A great many of these differences are well known. The characteristics of cannel coals and boghead coals are well known, so are the specific characteristics of a number of banded coals.

Although these types can be distinguished precisely and easily by the microscope, and differences in behavior are being recognized, means have not yet been devised of determining characteristics numerically; we have, therefore, as yet not enough numerical measurements to show

⁶ Younkins, J. A., and Davis, J. D., Effect of Fusain and Related Inerts on the Properties of Pittsburgh Coal with Particular Reference to Coking Properties. Work presented for Master's Thesis, Carnegie Institute of Technology, 1929.

specific differences. Engineers and technicians demand figures and curves. A beginning has been made by the U. S. Bureau of Mines in this respect by Fieldner and Davis⁷ and their co-workers. A number of coals are being examined with respect to certain physical properties, such as coking, gas- and oil-yielding and composition of these products, as well as the nature of the coke. Complete data of two well-known coals have thus far been obtained: a coal from the Pittsburgh bed from the Ocean No. 2 mine, and from the Elkhorn bed, mine 204, Jenkins, Fletcher County, Kentucky.

THE PITTSBURGH COAL

The Pittsburgh coal (Figs. 26, 27, 28 and 29) is a mixed anthraxylous-atrital coal. The anthraxylon is present as relatively thin sheets in innumerable numbers (Fig. 26). The attritus consists essentially of a humic-spore matter in which the humic matter predominates, with relatively little opaque and resinous matters present. Only occasionally are thin layers met with in which the opaque matter is prominent. The attritus in this coal, therefore, may be called a lucid-atritite. At the bottom of the bed the proportion of anthraxylon is greater than the attritus (Fig. 27). In going topward, the relative amount of anthraxylon decreases and the attritus increases proportionally so that at the top the relation of the two components has been reversed, being predominantly attrital toward the roof (Figs. 28 and 29).

THE ELKHORN COAL

The Elkhorn coal is distinctly an attrital coal with a relatively small amount of anthraxylon in exceedingly thin sheets, barely enough to make it a banded coal (Figs. 30, 31, and 34).

Distributed along the profile occur a number of typical splint coal bands (Figs. 30 and 31). There are seven in the column examined, varying in thickness from a few millimeters to three centimeters, their total thickness being 17 centimeters, and making approximately 2 per cent of the total thickness of the bed. The attritus is an opaque-spore-humic attritus—that is, humic matter, spore matter, and opaque matter are generally mixed. The opaque matter lends it splint coal characters (Fig. 32), and therefore, although this coal can not be called a typical splint coal, it has definite splinty characters. It is particularly rich in spore matter. No banded coal has as yet been found with as large a proportion of spores as this one.

⁷ Fieldner A. C., Davis, J. D., *Op. cit.*

In these two coals we have now numerical differences with respect to coking and by-products yield. Table 5 gives some of the results obtained by Fieldner and Davis.⁸

TABLE 5.—*Characteristics of two coals, according to Fieldner and Davis*

	Pittsburgh (Ocean No. 2 mine) (Forked lump)	Elkhorn (mine 204) (Run of mine)
Softening temperature of ash, degrees C....	1399	
Agglutinating power	6700	4300
Agde test fusion temperature, degrees C....	320	340
Agde test, decomposition.....	390	390
Plastic pressure, mm.....	1700 to 2300	440
Total bitumen, per cent.....	14.4	8.2
<i>Proximate analysis</i>		
Moisture	1.6	2.2
Volatile matter	34.2	36.6
Fixed carbon	56.7	59.0
Ash	7.5	2.2
	<hr/> 100.0	<hr/> 100.0
<i>Ultimate analysis</i>		
Hydrogen	5.4	6.1
Carbon	77.8	80.9
Nitrogen	1.6	1.5
Oxygen	6.6	8.7
Sulfur	1.1	0.6
Ash	7.5	2.2
	<hr/> 100.0	<hr/> 100.0

A more concise discussion of these coals has been given by Fieldner and Davis.⁸ Other coals are under investigation and it is hoped that more data will be obtained soon upon which more definite conclusions may be obtained for a more complete generalization.

PETROGRAPHIC CONSTITUENTS OF COAL ACCORDING TO EUROPEAN INVESTIGATORS

The various constituents in coal when massed in the coal lend a certain appearance to that layer of the coal in which massed. These layers vary in thickness and in some coals may comprise most of the bed or the whole bed.

The Europeans have given these layers or stripes various names according to their appearance, without special reference to their micro-

⁸ Fieldner, A. C., Davis, J. D., Reynolds, D. A., Determination of Gas-, Coke-, and By-Product Making Properties of American Coals. Read at Atlanta, Georgia, meeting of the Amer. Chem. Soc., April, 1930.

scopic composition. In England,⁹ the following terms are applied: vitrain, bright coal; clarain, striated bright coal; durain, hard or dull coal; fusain, mother of coal or mineral charcoal. In Germany,¹⁰ the following terms are applied for the same types of layers: Glanzkohle or vitrit, bright layers; Mattkohle or durit, dull layers; Faserkohle or fusit, mother of coal. The German investigators find the English term clarain to be superfluous. Recently, Lange¹¹ sub-classified the Glanzkohle and Mattkohle according to their petrographic appearance as follows:

1. Glanzkohle, mikrostreifig (micro-striped).
2. Glanzkohle, feinstreifig (finely striped).
3. Glanzkohle, grobstreifig (coarsely striped).
4. Feinstreifig, Glanzkohle and Mattkohle in the same proportions.
5. Mattkohle, feinstreifig.
6. Mattkohle, mikrostreifig.
7. Mattkohle, derb (non-striped).
8. Cannel coal.

But neither in England nor in Germany have they examined these petrographic components critically under the microscope, although results of a number of chemical and physical tests are available. There is as yet no unanimity of conception of the various terms used. Particularly confusing are the references to the terms Glanzkohle and Mattkohle. It is not quite clear whether Glanzkohle embraces only those unit constituents in coal derived from the woody parts, anthraxylon, or whether it embraces both anthraxylon and lucid-atrrite. So also with respect to the term Mattkohle, it is not quite clear whether it refers to coals containing predominantly opaque-atrrite or whether it refers to coals embracing both opaque-atrrite and the ordinary attritus or lucid-atrrite. For this reason a precise comparison can not be made, nor can their results obtained in physical and chemical determinations be applied precisely to all American coals.

⁹ Stopes, Marie C., On the Four Visible Ingredients in Banded Bituminous Coal. *Proc. Roy. Soc., B.*, vol. 90, 1919, pp. 470-487.

¹⁰ Hoffman, E., Aufbereitungstechnische Trennung der Petrographischen Kohlenbestandteile. *Glückauf*, vol. 66, pp. 529-540, 1930.

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Winter, H., Die Streifenkohle. *Glückauf*, vol. 55, pp. 545-555, 1919.

Winter, H., Mikroskopische und chemische Untersuchungen an Streifenkohlen des Ruhrbezirks. *Glückauf*, vol. 64, pp. 653-658, May 26, 1928.

¹¹ Lange, Th., *Op. Cit.*

Yet in general, British and European coal petrography shows of what constituents a coal is composed and in what proportions they occur beside each other. When it has been shown through chemical and physical investigation how the different components differ in structure and behavior, how they influence and disturb one another in combustion and when it has been found through practice how to use each component profitably, they are mined and separated and each sold for the particular purpose for which it is best suited. In the Ruhr district the separation of the constituents, particularly of the gas and gas-flame coals, has been found to be necessary and constitutes a real problem, as it probably will in all cases where it is attempted.

Recently, 58 coal beds of the Ruhr district in Germany were surveyed and the relative amounts of Glanzkohle, Mattkohle (splint coal), Faserkohle (fusain), and mineral matter in each bed were determined in percentages of the total thickness of the beds.¹² For this purpose a column of each bed was polished¹³ and then examined under the microscope and the total amounts of each ingredient were measured, so that it is now known exactly how much of each of these petrographic components is in each of the beds.¹⁴

By determining the behavior of each of these components in the manufacture of gas and coke and the yield of by-products, and also their burning characteristics under the boiler, the suitability of each for the various uses may be learned. With this knowledge it may be possible thereafter to separate the portions of a bed so that each component may be sold for its appropriate uses.

A similar survey has been carried out in the Lower Silesian coal fields.¹⁵ There, instead of working out the different components in percentages, graphic columns are constructed of a number of profiles of the coal beds on which the different types of coal are graphed in their relative thicknesses. Thus, a column so constructed shows at a glance the type of coal, how much there is of it, and where it is in the mine.

Because in Europe, particularly in Germany, great stress is laid on the differences in the chemical and physical properties of the three petrographic components—bright coal, Mattkohle, and fusain—considerable work has been done to show their differences. It is impossible to go into these data in detail, which in the last two years have become rather voluminous. A few examples will show the trend and give some idea.

¹² Lehman, K., u. Stach, E., *Die praktische Bedeutung der Ruhrkohlen petrographie*. Glückauf, vol. 66, pp. 289-299, 1930.

¹³ Stach, Erich, *Der Kohlenreliefschliff ein Neues Hilfsmittel für die angewandte Kohlen-petrographie*. Preussischen Geologischen Landesanstalt, 1927.

¹⁴ Lehman, K., u. Stach, E., *Op. Cit.*

¹⁵ Lange, Th., *Op. Cit.*

THERMAL DECOMPOSITION PRODUCTS OF VITRAIN AND DURAIN

Holroyd¹⁶ made an attempt to obtain definite information on the difference in the distillation under different temperatures of vitrain and durain in two British coals, one from the Hamstead coal and the other from the Barnsley coal. The Hamstead vitrain and durain give the following analyses (Table 6):

TABLE 6.—Analysis of Hamstead vitrain and durain

	Vitrain Per cent in pure coal	Durain
Moisture	13.40	6.40
Ash	1.30	6.00
Volatile matter	37.51	35.10
Carbon	78.32	80.92
Hydrogen	5.15	4.71
Nitrogen	1.02	1.08
Sulfur (organic)	1.01	0.97
Oxygen	14.50	12.32

Gaseous distillation products of Hamstead vitrain and durain (c.c. per 100 grams ash-free dry coal)

Carbon dioxide and sulfur dioxide.....	462	743
Higher olefines	193	166
Ethylene	122	80
Carbon monoxide	466	280
Hydrogen	230	279
Paraffin hydrocarbons	3517	2688
Total gas	4990	4236

Liquid distillation products of Hamstead vitrain and durain, per cent on ash-free dry coal

Water	8.20	6.98
Light oils	1.50	1.48
Heavy oils	5.82	7.74
Acidic oils	0.56	0.30
Phenolic oils	1.67	1.06
Basic oils	0.18	0.16
Hydrocarbons	1.75	3.69

The results from the Barnsby coal are similar.

Several German investigators¹⁷ have given us considerable information concerning the coking properties of the three or four petro-

¹⁶ Holroyd, R., and Wheeler, R. V., The Primary Thermal Decomposition of Coal: VI—The Comparative Distillation of Vitrain and Durain and the Behavior of the Morphologically Organized Plant Entities. *Fuel*, vol. 9, pp. 104-114, 1930.

¹⁷ Hock, H., u. Kühlwein, F. L., Gefügebzusammensetzung, Inkoklung und Verkoksbarkeit der Steinkohle. Glückauf, vol. 66, pp. 389-395, 1930.

Hoffman, E., Aufbereitungstechnische Trennung der Petrographischen Kohlenbestandteile. Glückauf, vol. 66, pp. 529-540, 1930.

Hoffman, H., Die makroskopischen Gemengteile der Saarkohle. Glückauf, vol. 64, pp. 1237-1243; 1273-1280, 1928.

Kattwinkel, R., Untersuchungen ueber die Verkoksbarkeit der Gefügebbestandteile von bituminösen Streifenkohlen des Ruhrbezirks. Glückauf, vol. 64, pp. 79-83, 1928.

Lange, Th., Der petrographische Aufbau des Sattelflöze Oberschlesiens. *Kohle und Erz*, vol. 25, pp. 791-802, 1928.

Rittmeister, W., Eigenschaften und Gefügebbestandteile der Ruhrkohlen. Glückauf, vol. 64, pp. 589-594; 624-637, 1928.

Winter, H., Die Streifenkohle. Glückauf, vol. 55, pp. 545-555, 1919.

Winter, H., Mikroskopische und chemische Untersuchungen an Streifenkohlen des Ruhrbezirks. Glückauf, vol. 64, pp. 653-658, May 26, 1928.

graphic components. They all agree that there is a great difference in their chemical and physical properties, particularly in their coking properties. The "Glanzkohle," or bright coal, always possesses good coking properties; the Mattkohle possesses no or poor coking properties, and fusain never possesses coking properties. Both, when mixed with a Glanzkohle have a deteriorating effect that makes itself particularly felt when exceeding 20 per cent.

Bright coal is therefore considered the most valuable constituent, as it possesses without a doubt the best coking properties and the largest amount of by-products—gas, ammonia, tar, and benzol.

Mattkohle, or splint coal may be used in coking when mixed in the right proportions with Glanzkohle, although alone and when mixed in too large proportions it yields a poor coke. When the Glanzkohle yields a coke too porous or too friable, a certain mixture of Mattkohle will improve the coke. When too large a proportion is used with Glanzkohle, it yields a poor, brittle coke. Mattkohle alone furnishes a dense, hard, and brittle coke.

Fusain comes in for much discussion. On account of the non-coking properties, its presence can only be deleterious. It does not yield many by-products.

Table 7 gives the relation between the four constituents.

TABLE 7.—*Relation of the coking properties of the four petrographic constituents as shown by the Meurice method, according to Kattwinkel*¹⁸

Coal mixture, per cent	Glanzkohle (anthraxylon) and fusain	Clarain and fusain	Mattkohle (splint) fusain	Glanzkohle (anthraxylon) Mattkohle (splint)	Clarain Mattkohle	Glanzkohle (anthraxylon) clarain
a : b	a : b	a : b	a : b	a : b	a : b	a : b
100 : 0	439	138	8	439	138	439
90 : 10	408	131	0	447	138	439
80 : 20	423	139	0	449	32	426
70 : 30	223	92	0	332	92	386
60 : 40	196	77	0	281	86	300
50 : 50	138	63	0	212	75	250
40 : 60	28	34	0	138	36	210
30 : 70	15	14	0	74	19	180
20 : 80	6	0	0	27	17	165
10 : 90	0	0	0	12	10	147
0 : 100	0	0	0	8	8	138

The foregoing figures give some idea of the different behavior of the petrographic components, as defined by them. A more minute microscopic examination reveals that in our coals many types of coals may be distinguished and so the problem is really more complicated than shown by the European investigators.

¹⁸ Kattwinkel, R., Untersuchungen ueber die Verkokbarkeit der Gefügebestandteile von bituminösen Streifenkohlen des Ruhrbezirks. Glückauf, vol. 64, pp. 79-83, 1928.

CONCLUSION

Much work is yet required in the examination of coals with respect to the nature of the ingredients, the different types of components involved, the determination of their relative amounts and a correlation with their behavior in the use of coal.

These remarks indicate only one line of research; there are other lines that are promising. The physical or colloidal nature of coal, for example, has hardly been touched.

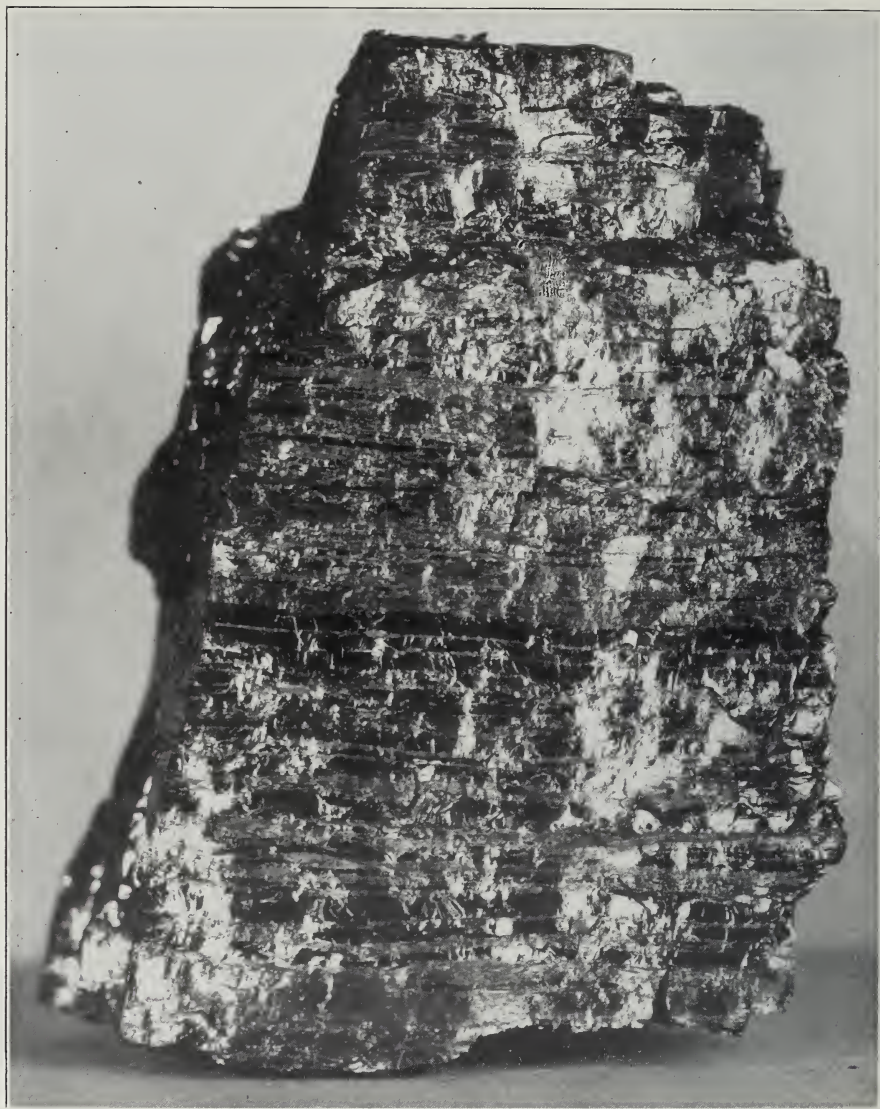


FIG. 11. Block of coal from the Taggart bed, Roda mine, Price County, Kentucky. This block shows the banding as found in most coals. The black bands represent the anthraxylon, the grayish appearing coal between the anthraxylon bands represents the attritus. (Slightly less than natural size)

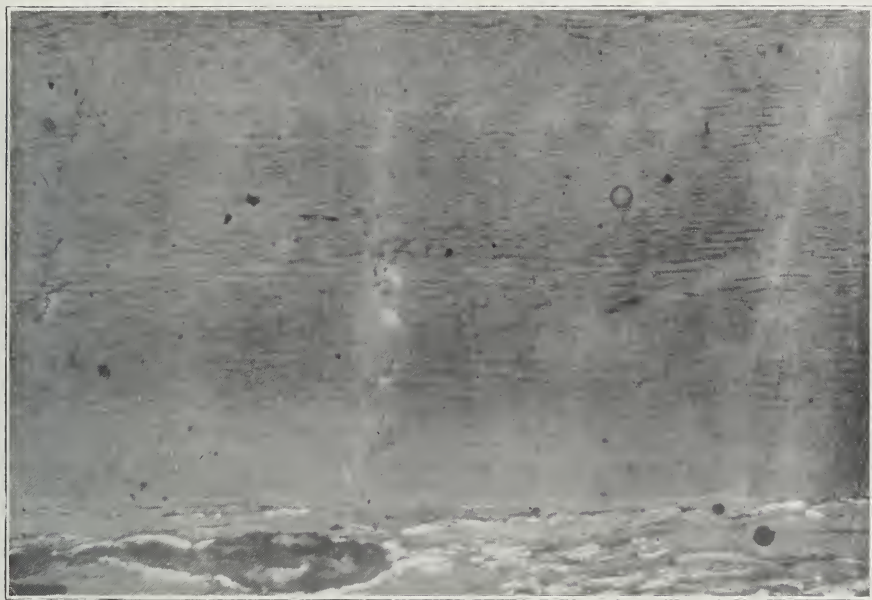


FIG. 12. Thin cross-section of coal showing part of anthraxylon in which the cell structure is poorly preserved, yet distinctly discernible. (X 200)

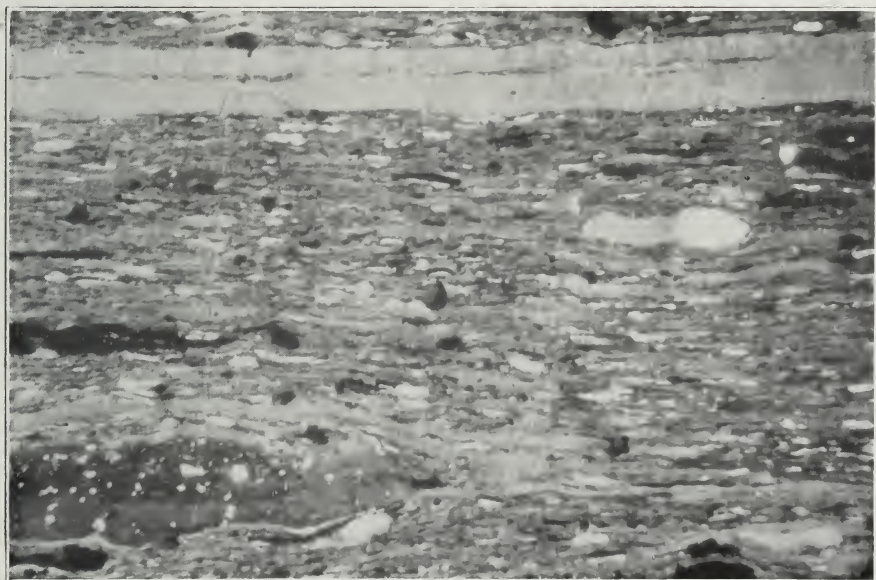


FIG. 13. Thin cross-section of coal from the Upper Freeport bed, showing a transparent attritus. In the upper part is imbedded a thin strip of anthraxylon. The attritus is composed of humic degradation matter, shown in gray; resinous matter, shown as more or less oval particles; spore matter, shown as short thin white patches; opaque matter, shown as irregular black spots; and fusain represented at the lower left corner of the figure. Compare also with Figures 18, 19, 20, 22, 24, 27, 28, 29 and 32. (X 200)

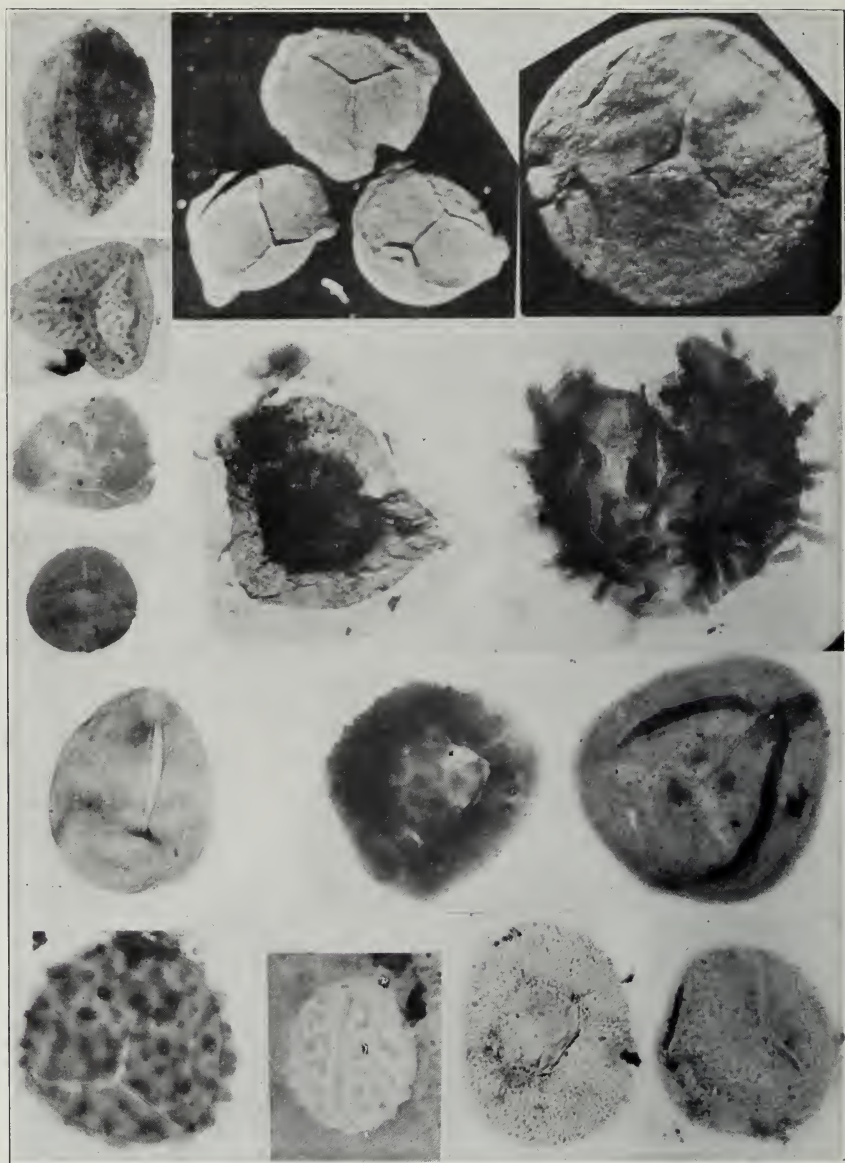


FIG. 14. Spores in coals. Different types of spores isolated from different coals and seen on the broad side.

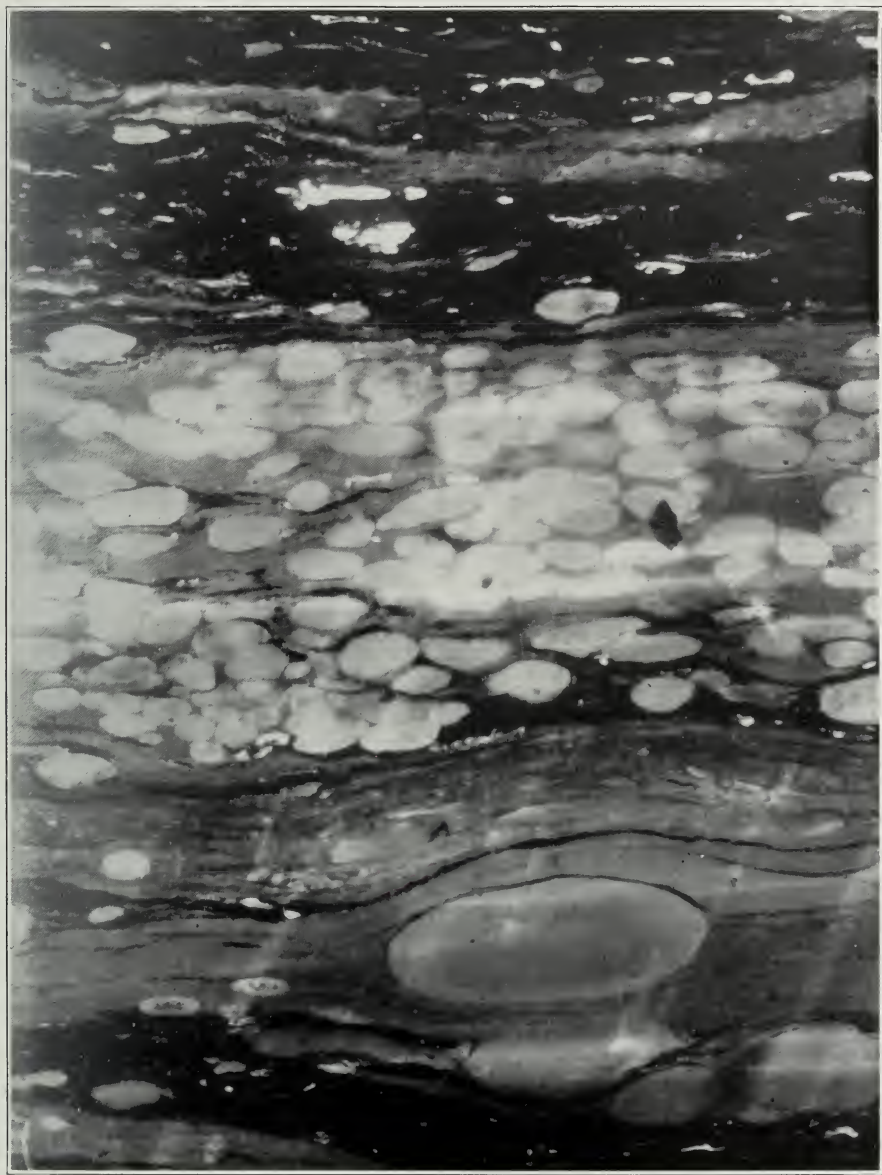


FIG. 15. Thin cross-section of coal from the High Splint bed, Closplint, Kentucky. This shows resin globules either inclosed in solid strands of anthraxylon or separate in the attritus. (X 200)



FIG. 16. Lump of coal from No. 6 bed, Old Ben mine, Franklin County, Illinois. This is a block of anthraxylous coal, and appears to be fairly typical of the coal in that mine. Note the broad bands of anthraxylon and compare with thin layers of attritus. See also Figures 11, 21, 26, and 30. (Slightly less than natural size)

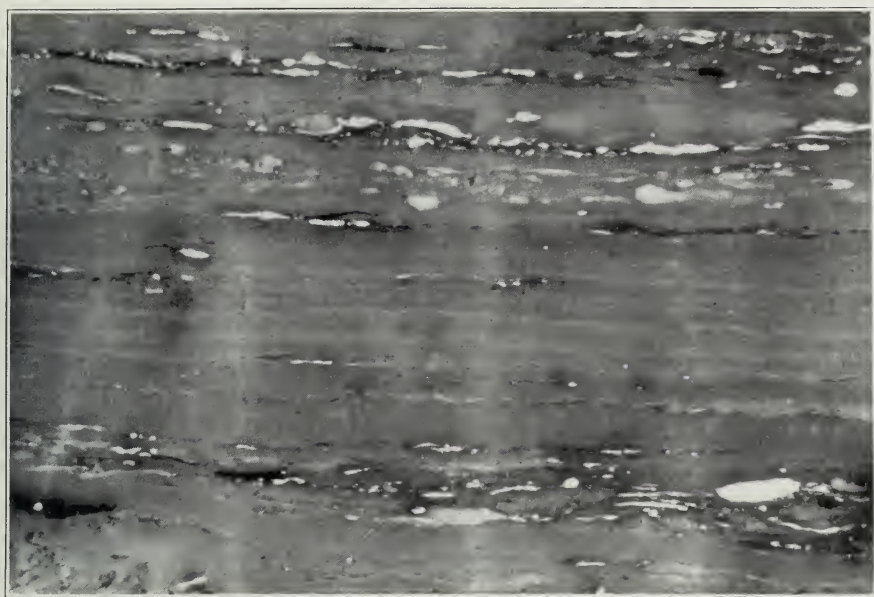


FIG. 17. Thin cross-section of coal from No. 6 bed, Old Ben mine, Franklin County, Illinois, showing the characteristics of an anthraxylous coal. - Note the small amount of attrital matter. (X 200)

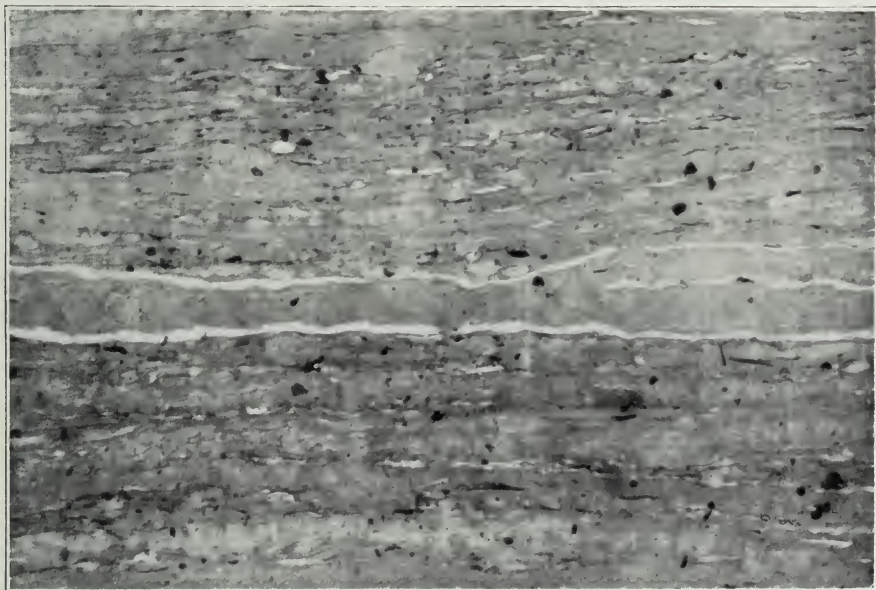


FIG. 18. Thin cross-section of Redstone coal, showing an attritus composed largely of humic matter. Very few spores are present. In the middle of the section is a strip of tissue bounded on either side by a cuticle. (X 200)

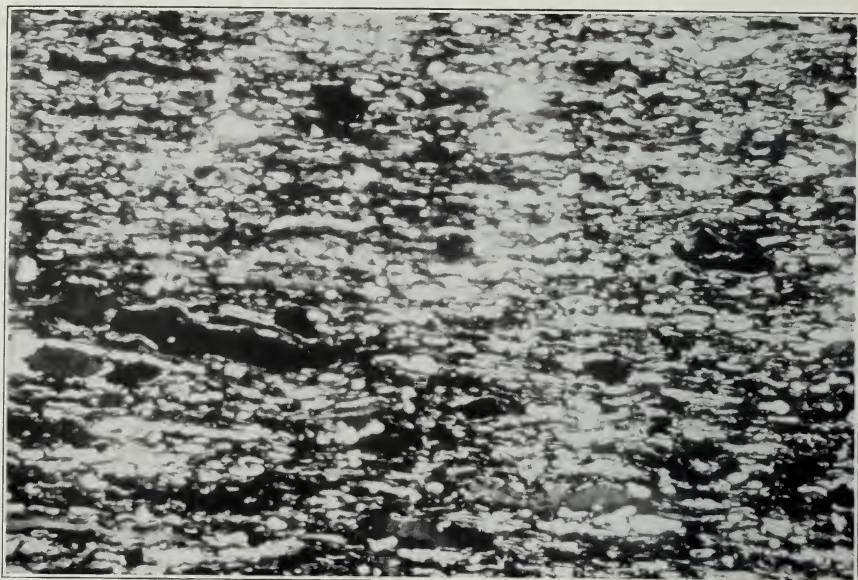


FIG. 19. Thin cross-section of the attritus of a spore coal. Spores, shown in white, form the predominant part; only relatively a small part of humic and opaque matter is present. (X 200)

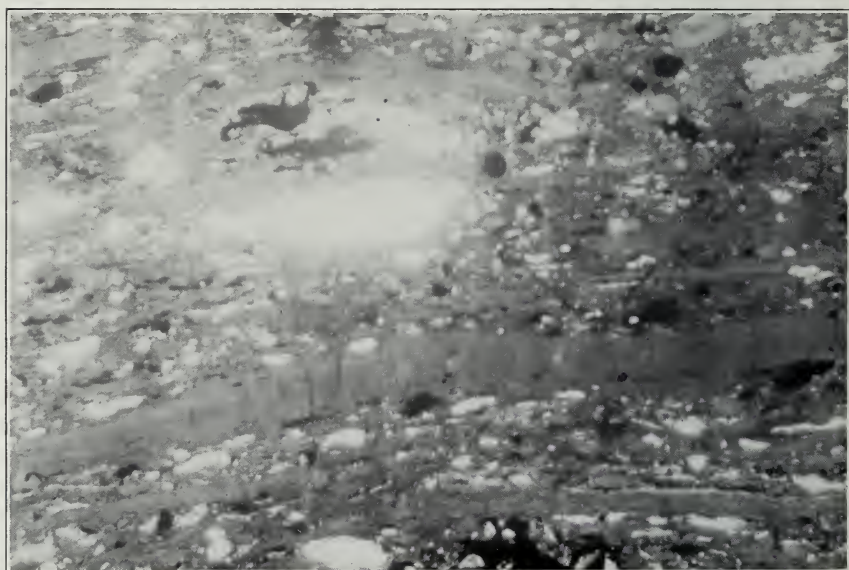


FIG. 20. Thin cross-section of coal from Sunnyside mine, Utah. In addition to the humic matter, the attritus in this coal contains a large proportion of resin in the form of irregular granules of greatly varying sizes and of a light yellow color. (X 200)



FIG. 21. A block of splint coal from the High Splint bed, Closplint, Harlan County, Kentucky. Characteristics of the splint coals are the large number of relatively thin anthraxylon sheets, and the relatively large amount of attritus. The attritus in this coal is composed largely of opaque matter, spores, and some humic and resin matters. (Slightly less than natural size)



FIG. 22. Thin cross-section of splint coal from the High Splint bed, Harlan County, Kentucky. The ground mass consists of opaque matter and in a medium thin section is entirely opaque, only the spores, occasional resin particles, and strips of humic matter being transparent. (X 200)

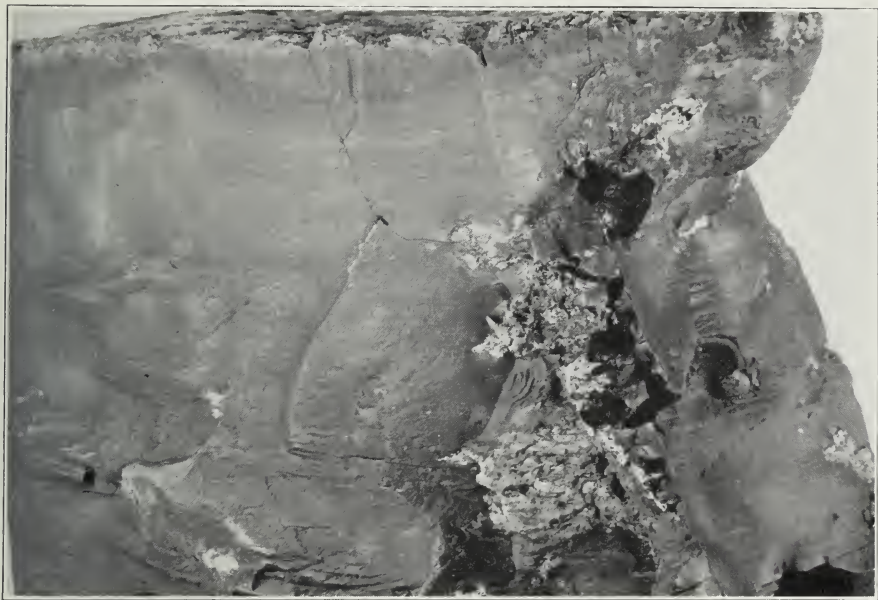


FIG. 23. Block of cannel coal from Cannelton, Beaver County, Pennsylvania. This is a spore cannel coal. See Figure 24. (Natural size)



FIG. 24. Thin cross-section of cannel coal from Cannelton, Beaver County, Pennsylvania. This cannel coal is composed largely of spores, some humic matter, some resinous matter, and some opaque matter. (X 200)

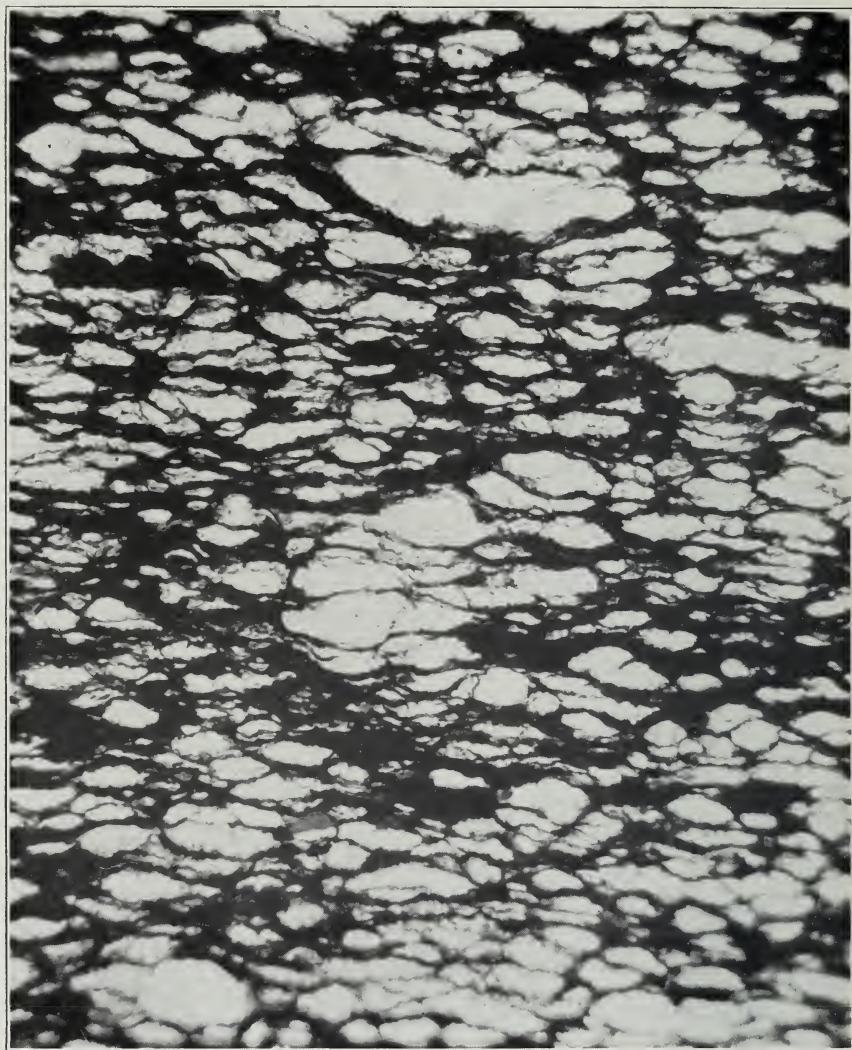


FIG. 25. Thin cross-section of boghead coal from Alaska. The white bodies are the so-called yellow bodies, the remains of oil algae. (X 200)



FIG. 26. Block of Pittsburgh coal. This is compiled of innumerable thin anthraxylous sheets, embedded in equally thin layers of atritus. See also Figures 27 and 28. (Slightly less than natural size)

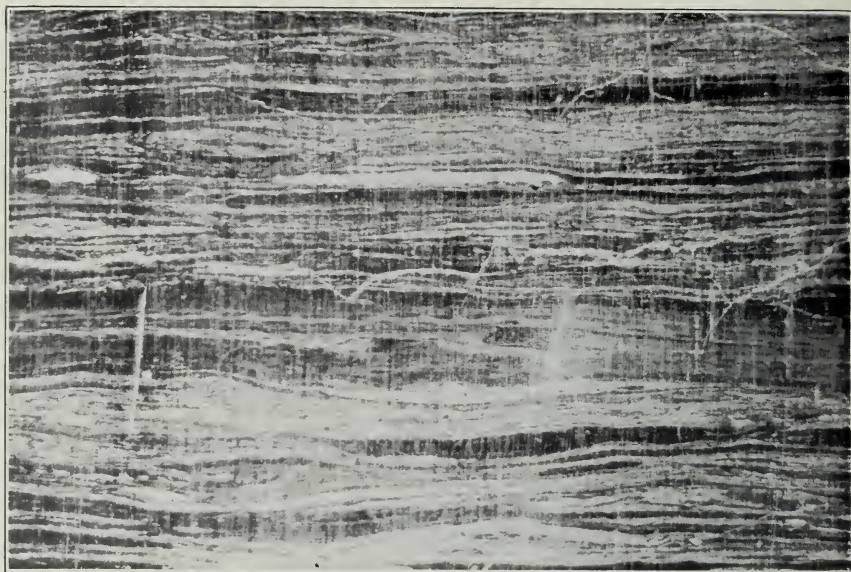


FIG. 27. Polished surface of Pittsburgh coal from the U. S. Bureau of Mines Experimental mine, taken from the lower part of the bed, and containing a larger proportion of anthraxylon than attritus. (X 10)

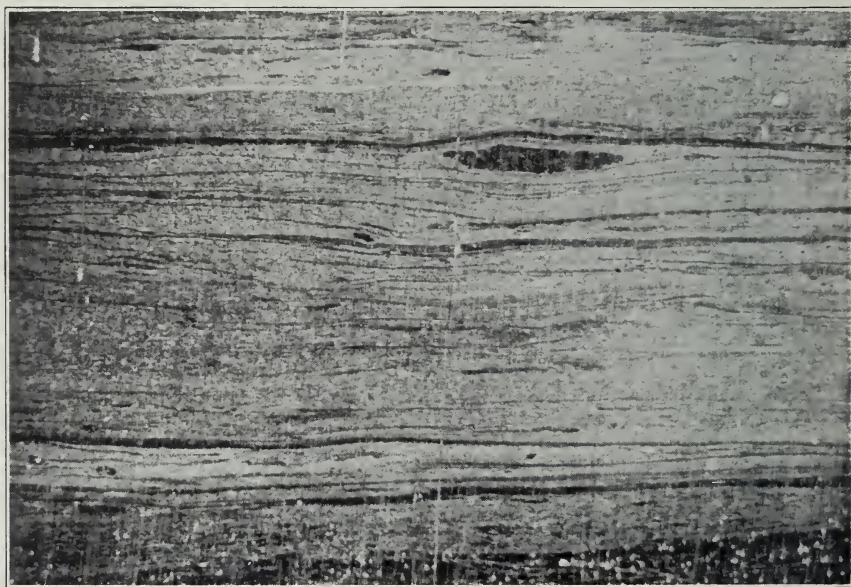


FIG. 28. Polished surface of Pittsburgh coal showing the appearance of the attritus at a low magnification, taken from the upper part of the bed and containing a larger proportion of attritus than anthraxylon. Note that only relatively few thin strips of anthraxylon, shown as black stripes, are embedded in the attritus. Figure 29 shows the attritus of a similar section at a magnification of 200 diameters. (X 10)

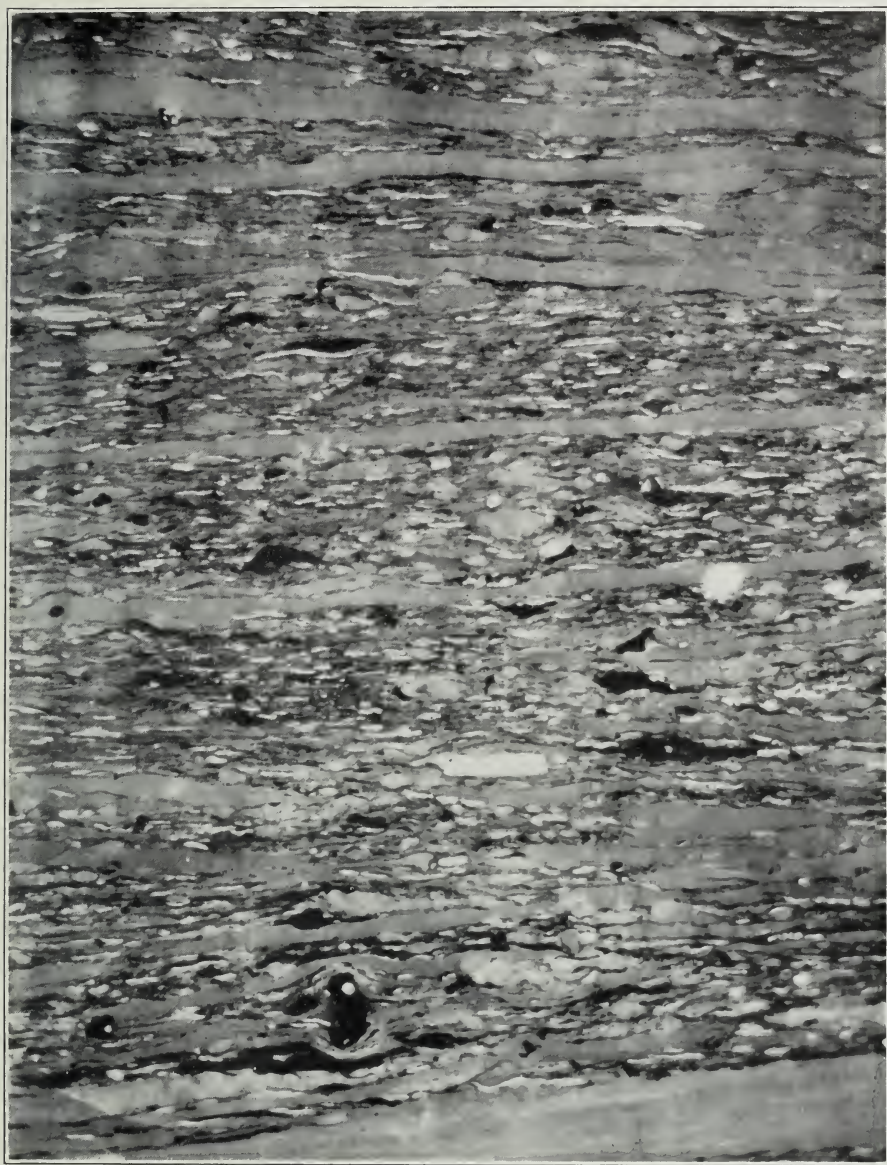


FIG. 29. Thin cross-section of attritus of Pittsburgh coal, taken from a section similar to that shown in Figure 28. This is a typical transparent attritus (lucid-attrite) of the Pittsburgh coal. It is composed essentially of humic matter, spore matter, a small amount of resinous matter and of opaque matter. (X 200)



FIG. 30. Block of Elkhorn coal, mine 204, Jenkins, Fletcher County, Kentucky. In the upper part of the block the coal is compiled of a large number of thin strips of anthraxylon and attritus, below this is a band of typical splint coal, approximately 1.5 centimeters thick. The coal below this, forming the larger part of the block, is composed largely of attrital matter, including relatively little anthraxylon in thin sheets. (Slightly less than natural size)

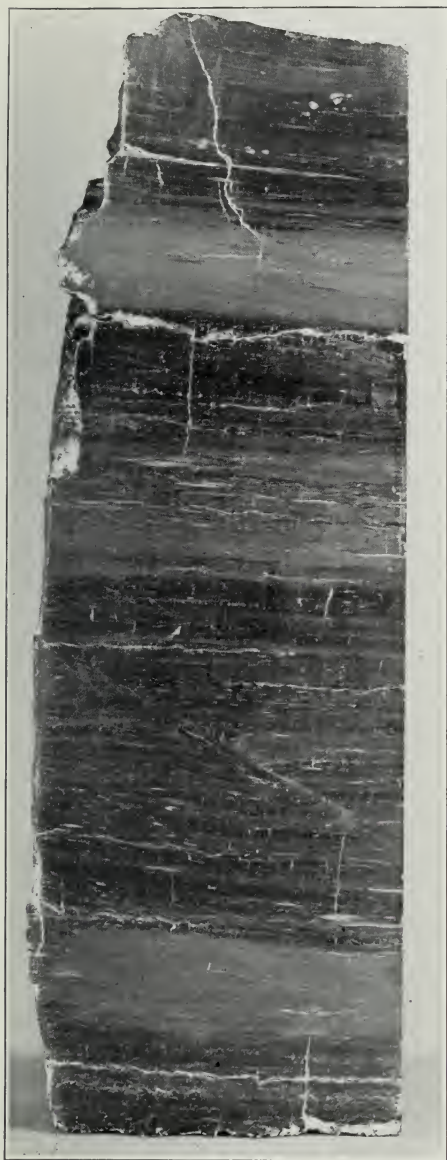


FIG. 31. Polished surface of Elkhorn coal, mine 204, Jenkins, Fletcher County, Kentucky, block from about the middle of the bed. Toward the top and the bottom of the block are bands of typical splint coal. The main part consists of attrital matter, composed of a mixture of humic matter, spore matter, and opaque matter, and relatively little anthraxylon. (Less than natural size)

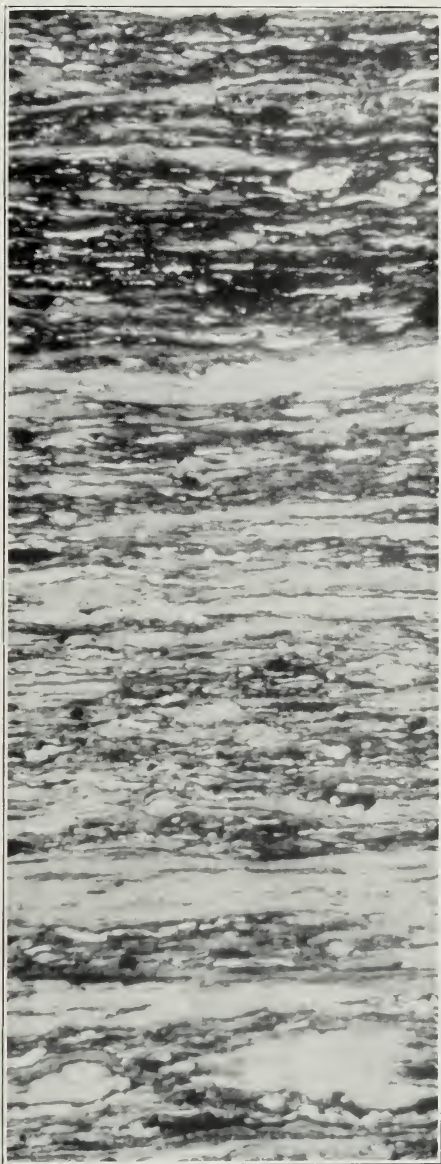


FIG. 32. Thin cross-section of Elkhorn coal, mine 204, Jenkins, Fletcher County, Kentucky. This shows the attritus typical of the Elkhorn coal. It is composed essentially of a mixture of humic matter, opaque matter, spores, and a little resinous matter. The proportions of these ingredients varies some in different horizons. Spores are generally abundant. (X 200)



